NASA SPACE TELEROBOTICS HIGHLIGHTS - PART I

PRESENTATION AT ROBOTICS EXHIBITION
PALMERSTON NORTH SCIENCE CENTRE
NEW ZEALAND, MAY 31, 1994

C.R. WEISBIN, PROGRAM MANAGER
ROVER AND TELEROBOTIC TECHNOLOGIES
JET PROPULSION LABORATORY, USA

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    - » (Satellite Test Assistant-JPL; Microsurgery-JPL)
  - Planetary Exploration
    - » (Ambler, Dante - CMU; Robby, Rocky- JPL)
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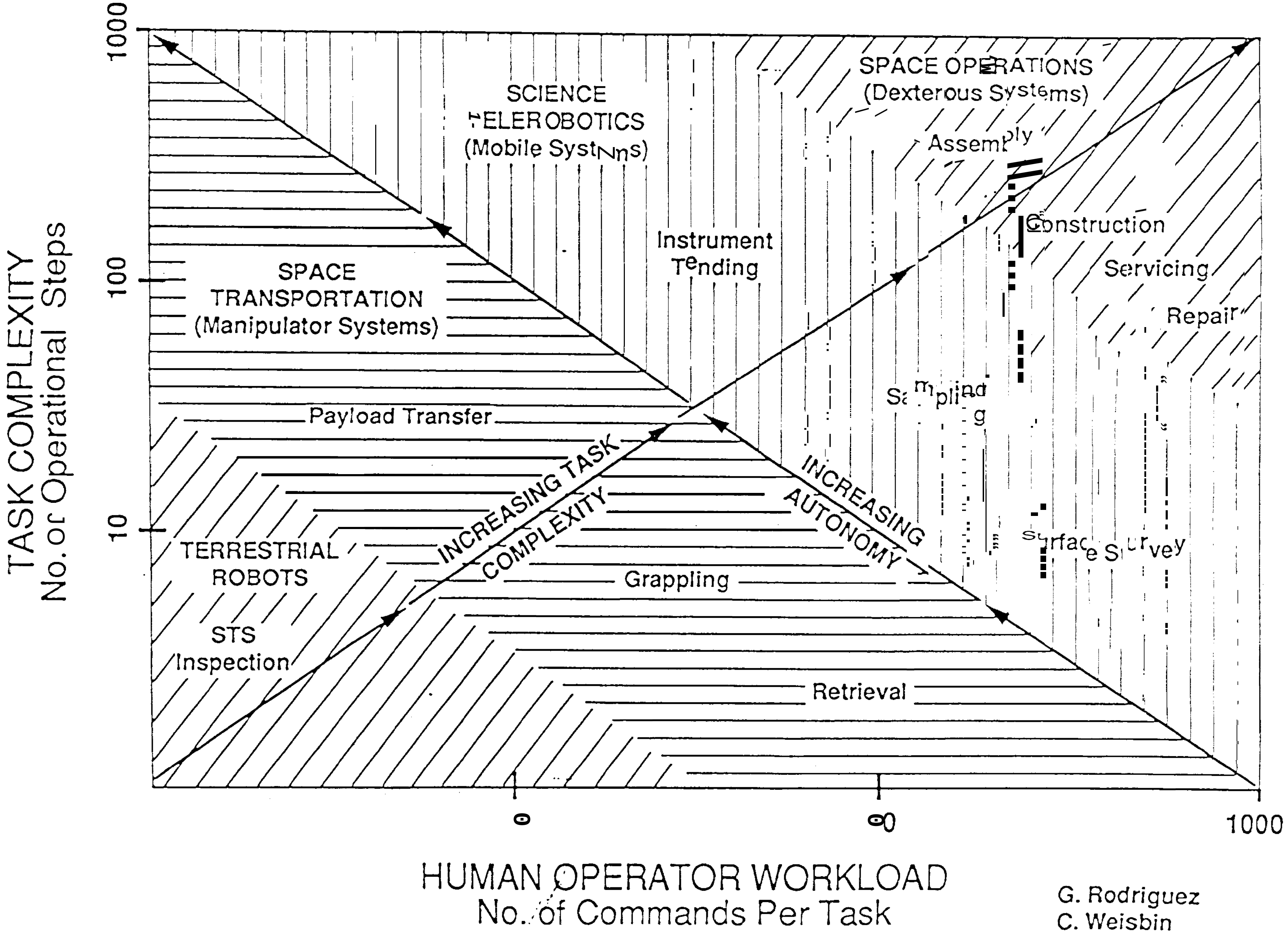
- Near Term and Grand Challenges

NASA TELEROBOTIC TECHNOLOGY: STRATEGIC GOALS

- DEVELOP AND DELIVER THE TECHNOLOGIES REQUIRED TO ENABLE 50% OF ALL ON-ORBIT SERVICING AND PLANETARY EXPLORATION TO BE PERFORMED WITHOUT EVA BY 2004.
- REDUCE COSTS OF NASA TERRESTRIAL OPERATIONS AND POSITIVELY IMPACT THE U.S. ROBOTICS INDUSTRY
  - Agriculture
  - Hazardous operations
  - Microsurgery

SPACE TASKS ENABLED BY TELEROBOTIC SYSTEMS



G. Rodriguez
C. Weisbin

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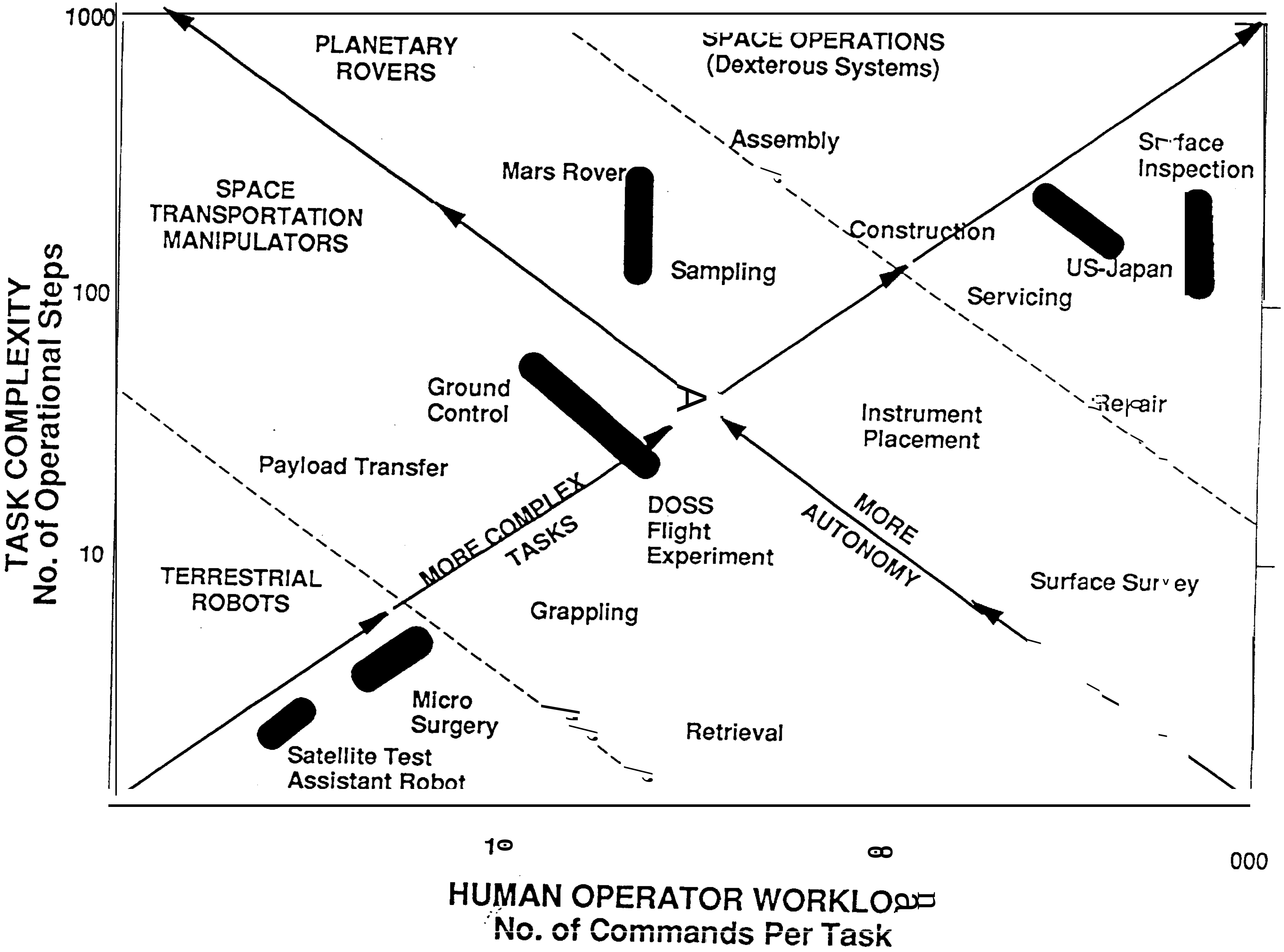
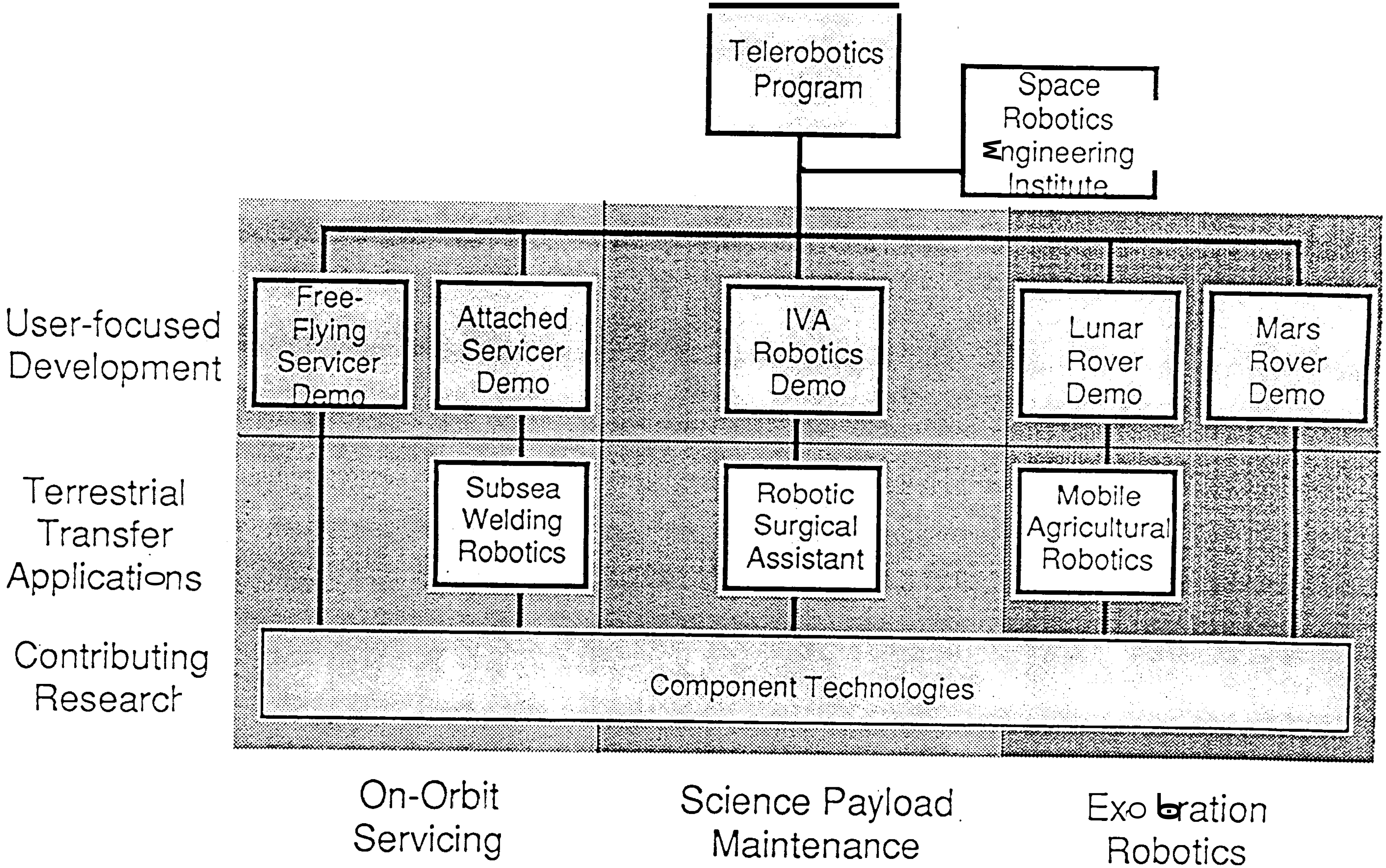


Telerobotics Program Organization



Telerobotics Program

TELEROBOTICS PROGRAM

PARTICIPANTS:

- JPL (lead center)
- ARC
- GSFC
- JSC
- KSC
- LaRC
- CMU
- U. Maryland
- MIT
- Stanford
- U. Texas

PRODUCTS:

- Automated Inspection Robots
- Robotic Assembly Systems
- Microrovers
- Ground/Flight Demonstrations
- Robotic Servicing Systems
- Robot Architectures
- Fault-Tolerant Mechanisms
- Students and Publications

MISSION APPLICABILITY:

- Space station RMS, SPDM
- Remote satellite repair
- Earth orbiting missions
- Planetary surface operations

EMPHASIS OF PARTICIPANTS

- JPL- Lead Center with R&D in most areas
- JSC- Space Station Maintenance and Repair
- U. Md- Neutral Buoyancy; Free Flyer Expt.
- CMU- Lunar exploration; Rovers for Farming
- Stanford- Supervisory Control, Manipulation
- LaRC- Space Station Maintenance
- GSFC- Obstacle Avoidance, Actuator Design
- KSC- Shuttle Launch Processing
- ARC- Applied Virtual Reality Technology

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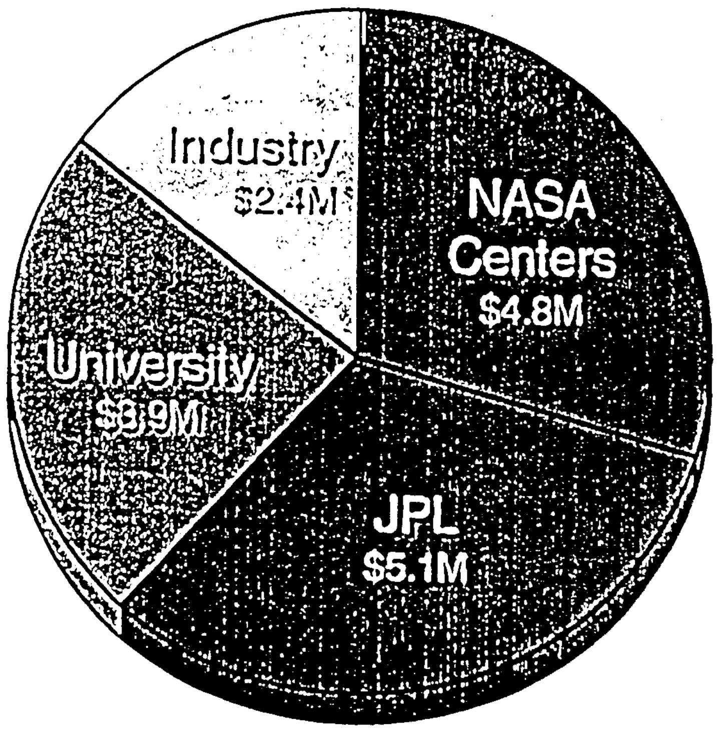

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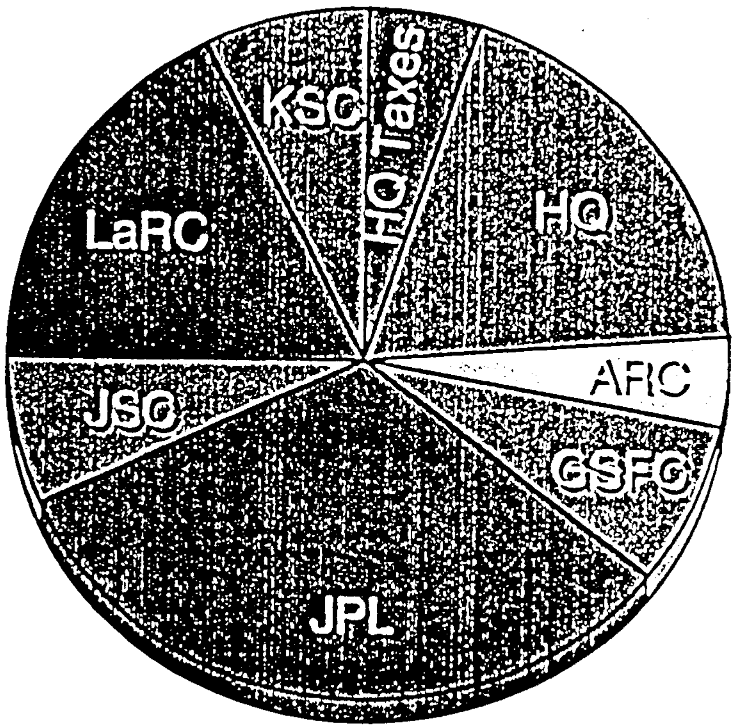

By NASA field center

Source: FY *1993* Telerobotics Program Plan.
Includes focussed program, base R&T
program, and forward-funded FY 1992 tasks

Telerobotics Program

UNIQUE NASA TELEROBOTICS TECHNOLOGY REQUIREMENTS

- NASA has unique needs in telerobotics technology
  - Time-delayed telerobotic systems (~8 sec. to earth-orbit, ~ 40 min. to Mars)
  - Mobile micro-rover and free-flying vehicles
  - Moveable-base and limber manipulators
  - Light and low-power flight telerobots
  - Low-mass, low-power advanced flight computing

- Related technology in other programs
  - Robot control architectures (NET, RPI, etc.)
  - Natural terrain navigation (DARPA)
  - Maneuverable robots (Underwater Robotics)
  - Long-reach arms (Nuclear Waste Management)

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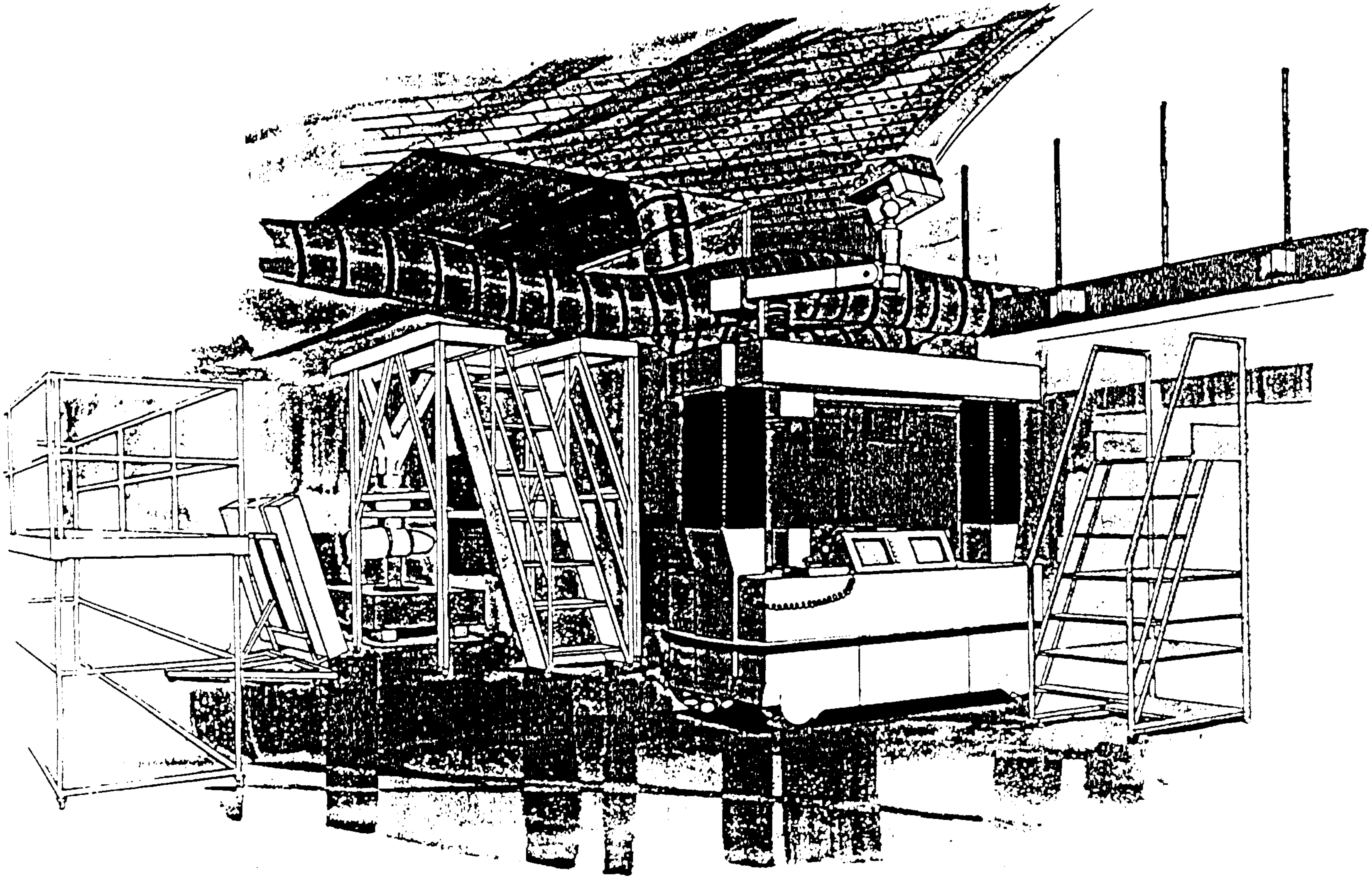
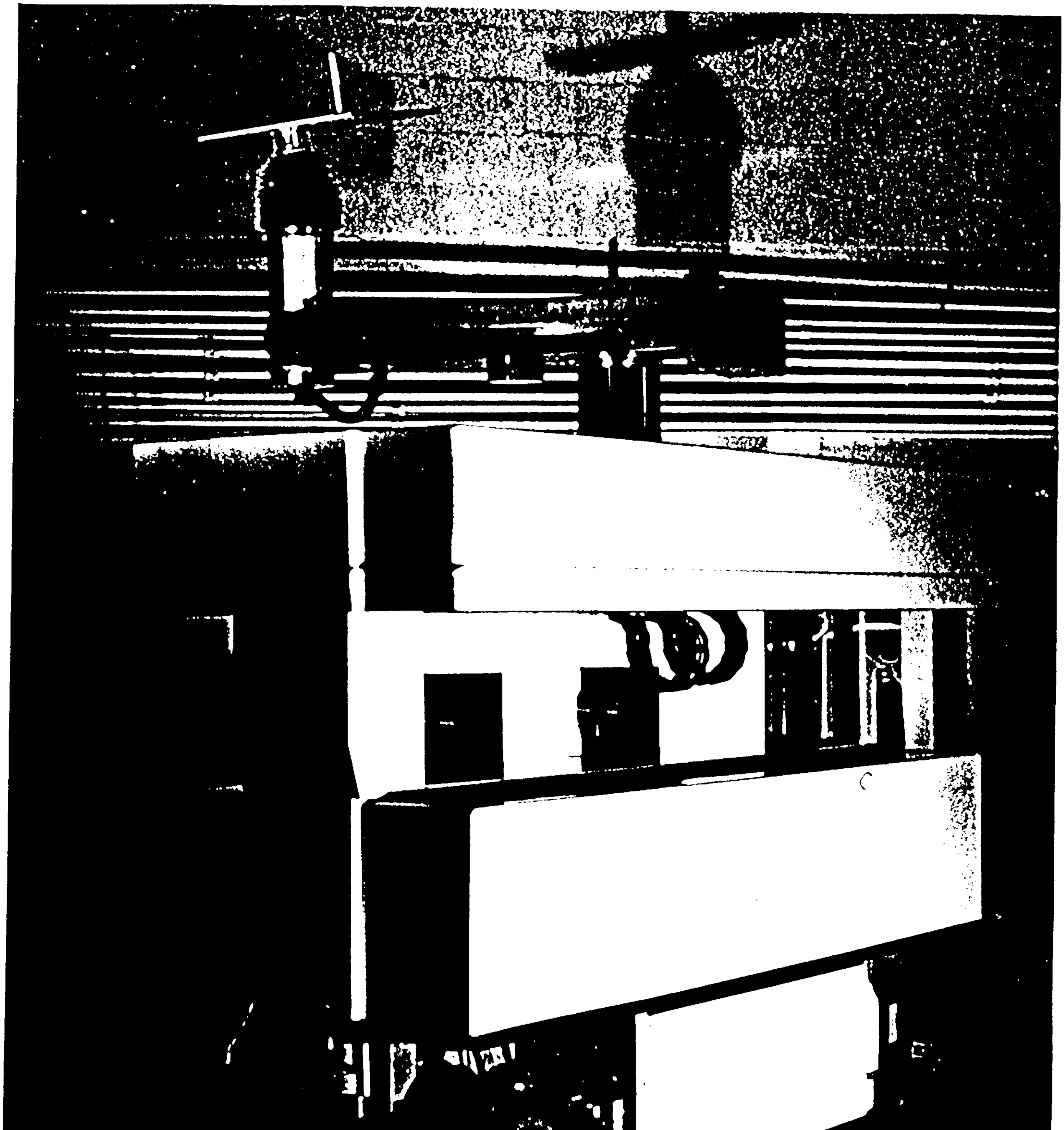
  - Embedded computer system software (DoD, DARPA)

TILE INSPECTION PROTOTYPE ROBOT



STS TILE INSPECTION AND MAINTENANCE (KSC)

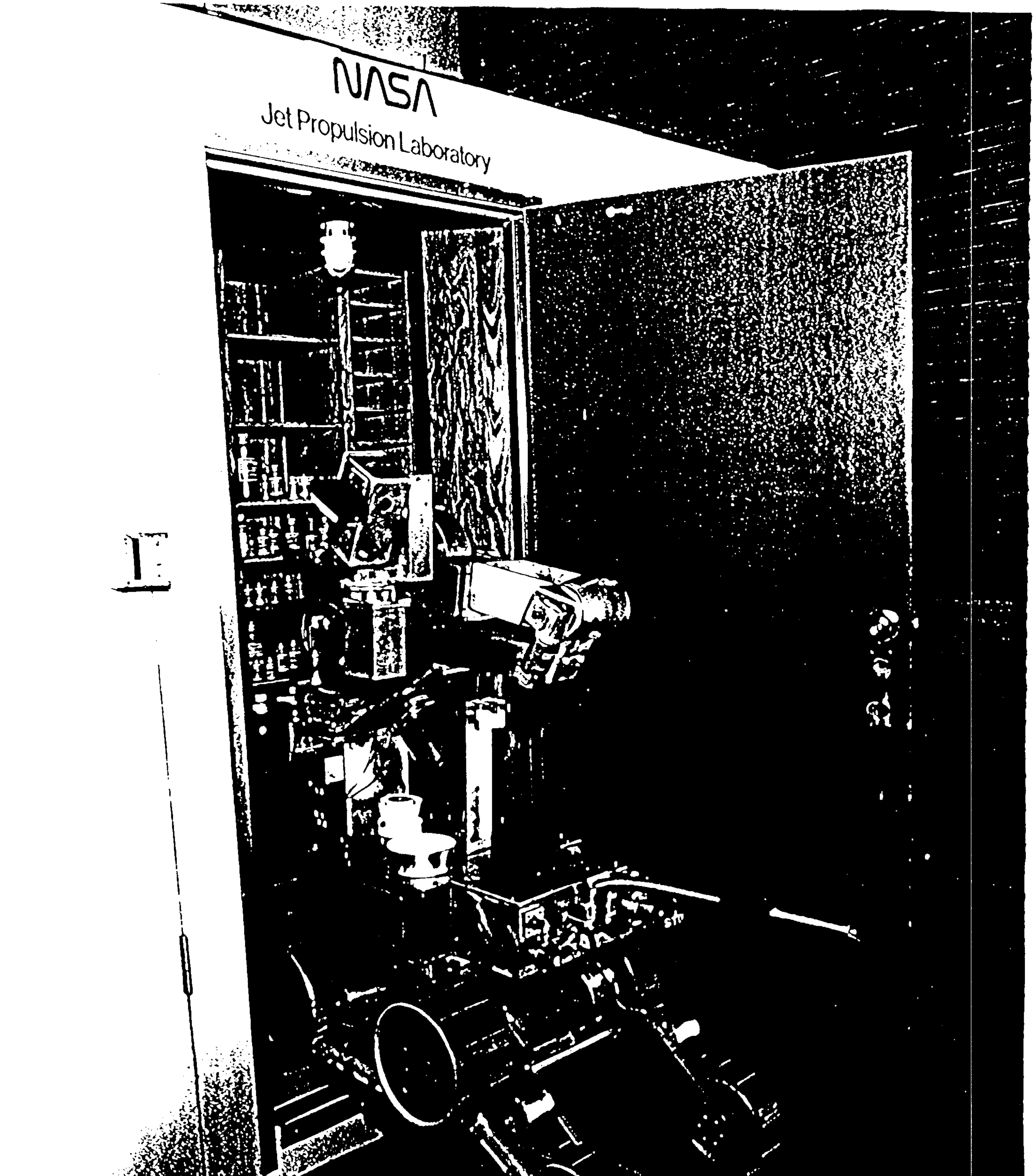
- Major System Demonstration Conducted
  - Mobile base manually and automatically operated
  - Global location and positioning system shown
  - Tile mapping system demonstrated
  - Re waterproofing end effecter operated with real STS tile array
  - Vision system correctly identified and characterized tile dings
- Demo Of Vision System Integrated With Mobile Base



JPL

PROJECT OBJECTIVES

- **Develop a teleoperated mobile robot that can be controlled by Safety and HAZMAT Team personnel to :**
  - Gain access to HAZMAT incident sites which may require climbing stairs ,unlocking and opening doors, and moving in confined spaces
  - Identify materials involved via visual inspection and remote chemical sensing
  - Aid in incident mitigation by, for example, deploying absorbent pads or turning off valve
- **Work directly with end-user of technology - JPL Fire Department HAZMAT Team -to establish system requirements as well as use and critique the system**
- **Use commercially available technology whenever possible and transfer new technology back to US industry**


NASA
Jet Propulsion Laboratory

JPL

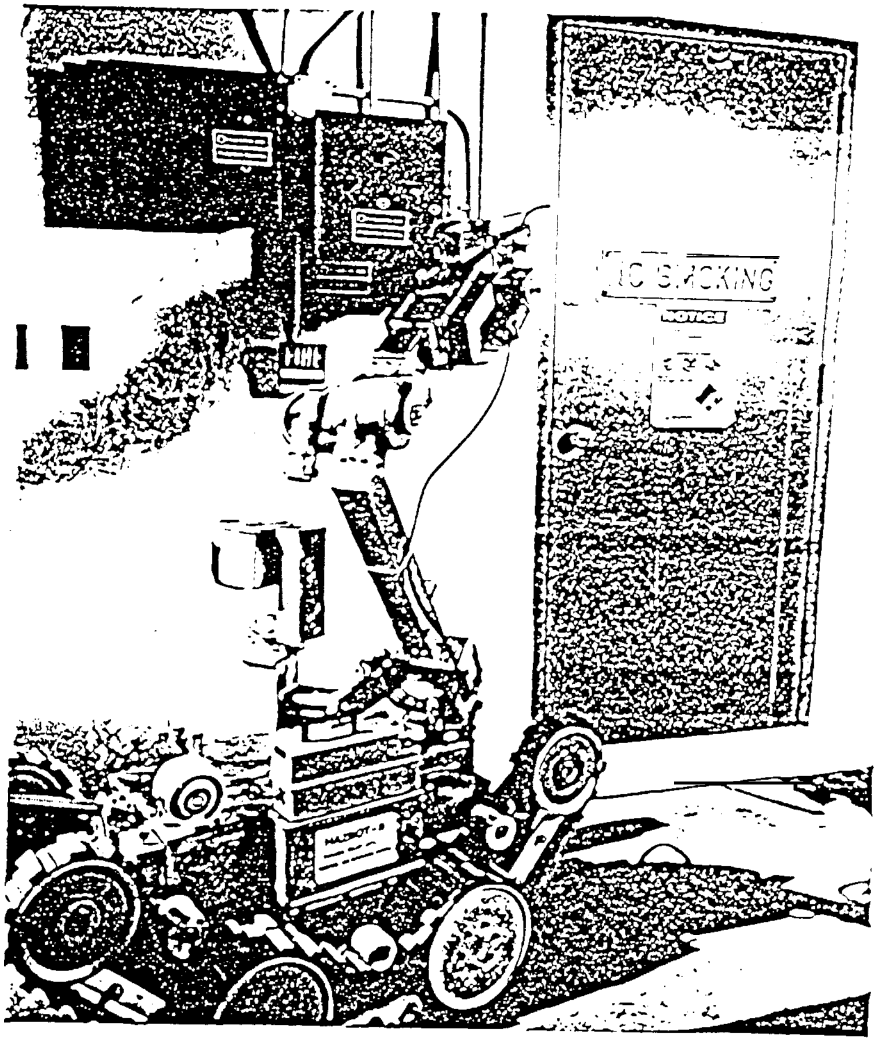
BENEFITS

- REDUCTION IN RISK TO HUMAN LIFE/INJURY
- REDUCTION IN INCIDENT RESPONSE TIME
- POTENTIAL FOR SHORT TERM DELIVERABLES "QUICK WINS"
- APPLICATION TO SPACE FLIGHT OPERATIONS INVOLVING HAZARDOUS MATERIALS AND/OR OPERATING CONDITIONS

PRE-ENTRY HAZARDOUS MATERIALS LOCALIZATION AND IDENTIFICATION

HUMAN ENTRY TEAM

HAZBOT-II



JPL

HAZARDOUS MATERIALS INCIDENTS-JPL

•EXAMPLES:

Sulfuric Acid Spill (PaHet of batteries dropped during delivery)-1 988, Level B (Proper equipment not available at time of incident).

Hydrogen Fluoride Faulty Cylinder Regulator (Threatened Release)-Building '189, November 1989, Level C (Should have been Level A; proper equipment not available at time of incident).

Anhydrous Ammonia Leak-Building 111, March 1990, Level B

Propane Leak-Building 264, October 1990, Level C

JPL

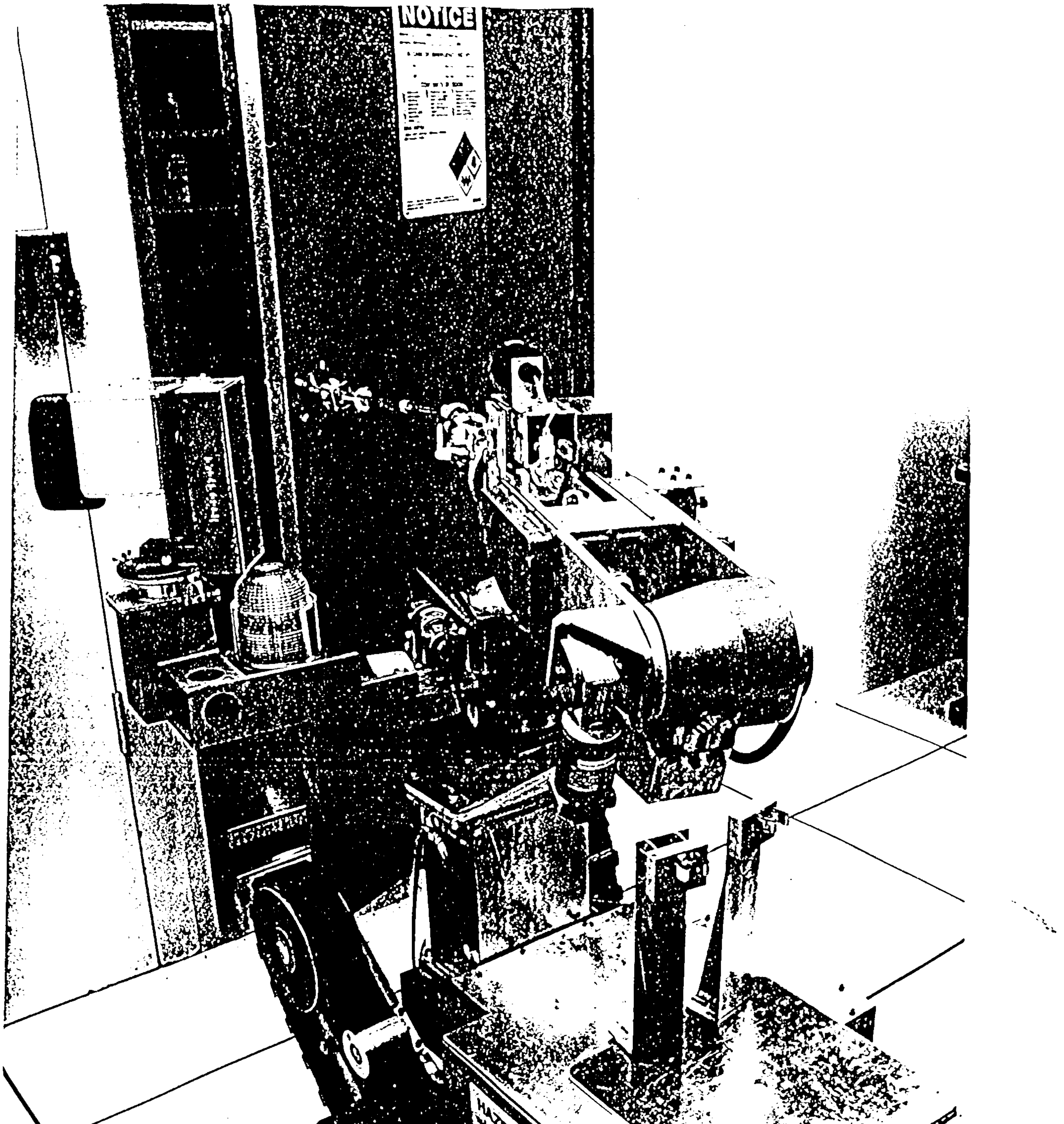
HAZARDOUS MATERIALS INCIDENTS-JPL

- **EXAMPLES:**
  - Sulfuric Acid Spill-Cryogenics Dock, September 1990, Level B
  - 111 Tricloroethane Spill-Building 111, September 1990, Level B
  - Phosphine Leak (Faulty cylinder) Class A Poison/Toxic Gas-Building 302, November 1990, Level A. (Storage in hydrogen created additional explosive danger).
- **STATISTICS**
  - Incidents requiring Level B suitup-1 incident/2 weeks (average)
  - Oxygen Deficiency testing-6 times/week (average)

JPL

1ST YEAR ('91)

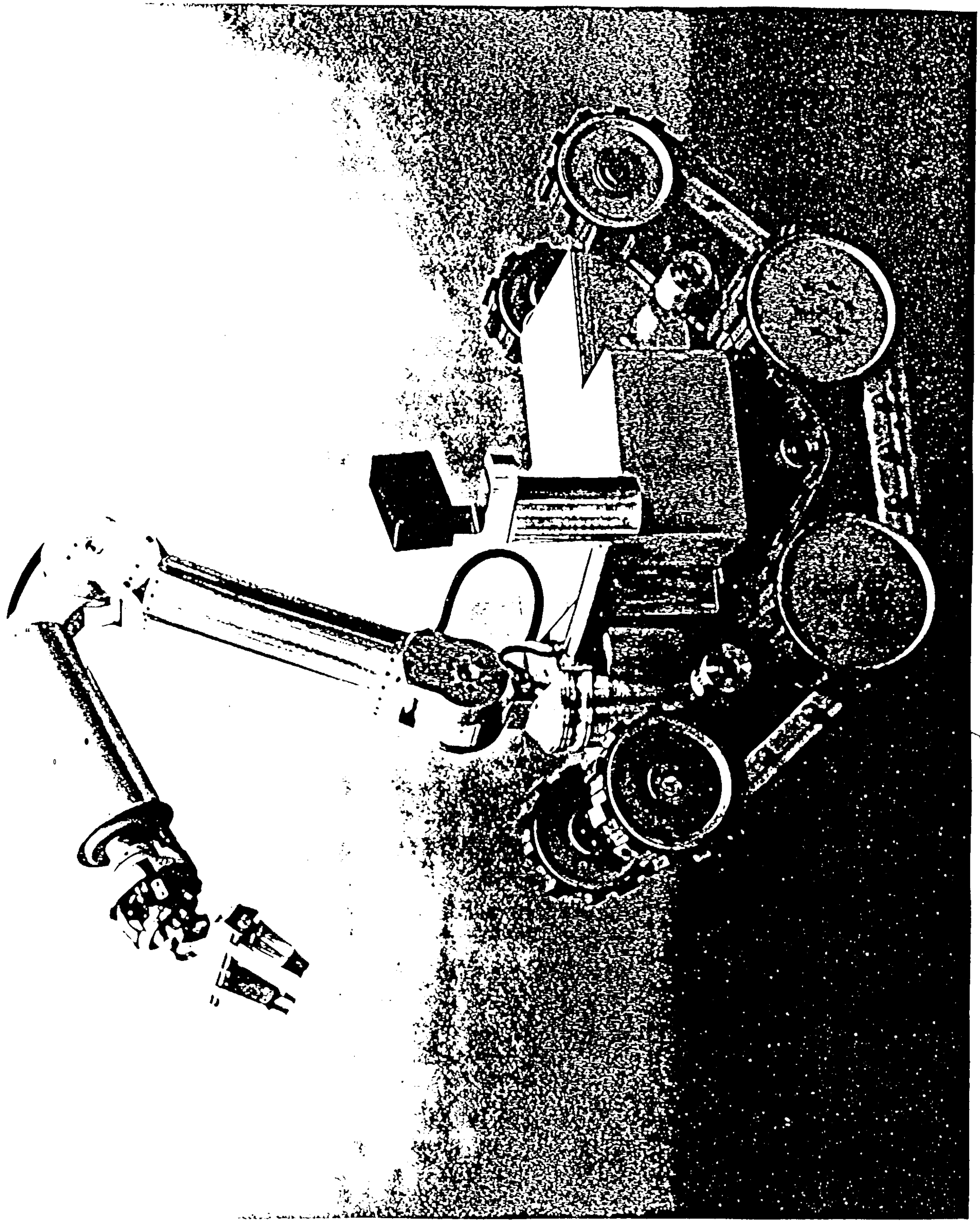
- **Procured commercially available mobile robot to use as a base design**
- **Identification of system modifications to aid in HAZMAT missions:**
  - Improvement of operator interface and feedback
  - Increase speed and stiffness of manipulator without loss in load capacity
  - Redesign system to have smooth profile to ease decontamination and reduce chance of snagging during a mission
  - Development of special tools to enable doors to be unlocked and opened
  - Addition of chemical gas sensor to aid in material identification
  - Redesign of robot for operation in potentially combustible atmospheres
- **HAZBOT II Demonstration - reconnaissance mission** to **chemical storeroom**


NOTICE
HAZBOT

JPL

MAJOR ROBOT REDESIGN ('92 & '93)

- Place **all motors and electrical/computer components in pressurized enclosure**
  - Enable operation in combustible atmosphere
  - Provide smooth exterior for decontamination
- **Use all solid state electronics and bushless motors**
  - Non-arcing electrical components for operation in combustible atmospheres
- **Upgrade computer system**
  - Enable addition of on-board sensors
  - Allow closed-loop control of manipulator to increase dexterity
- **Add chemical gas sensor**
  - Specific sensors for oxygen and carbon monoxide
  - General combustible gas sensor



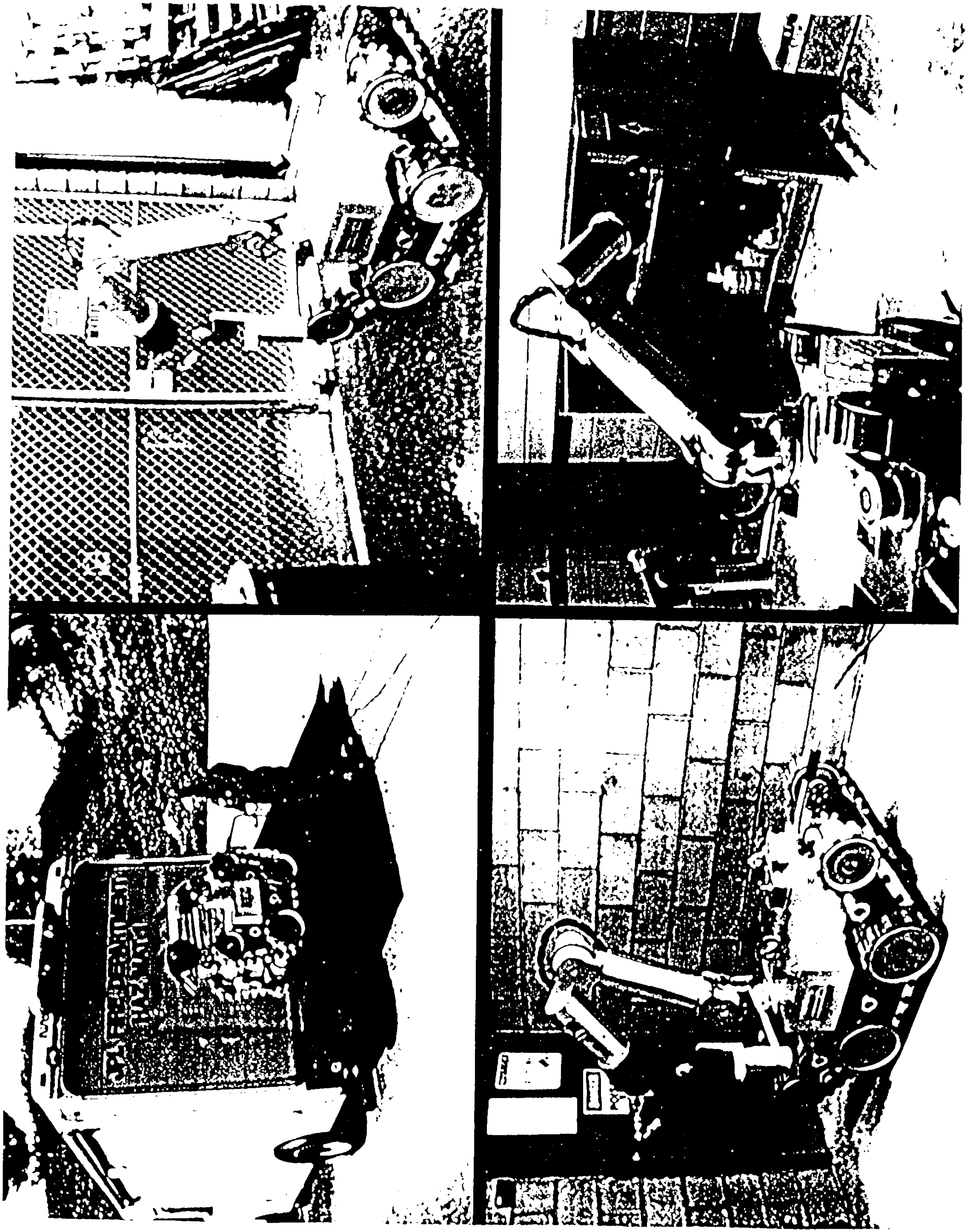
OTHER APPLICATIONS

- REMOTE **MONITORING AND SAMPLING**
  - New and existing hazardous material sites
  - Large industrial complexes
- **LAW ENFORCEMENT**
  - Bomb disposal
  - Hostage situation
  - Armed standoffs
  - Surveillance
- MINING **OPERATIONS**
  - Response after cave-in or accident
  - **Demining** battlefields, airport runways, etc.

JPL

CURRENT ACTIVITIES

- **PREPARING HAZBOT 111 FOR FIELD OPERATIONS WITH JPL HAZMAT TEAM**
  - Ready for field operation (at least for reconnaissance).
  - Simulated emergency - operators not informed ahead of time
- **DEVELOPING NEW OPERATOR CONTROL STATION**
  - Graphical display of system and sensor data
- EXPLORING OTHER **AREAS INCLUDING:**
  - RF link for tetherless operation
  - Stereo vision system



JPL

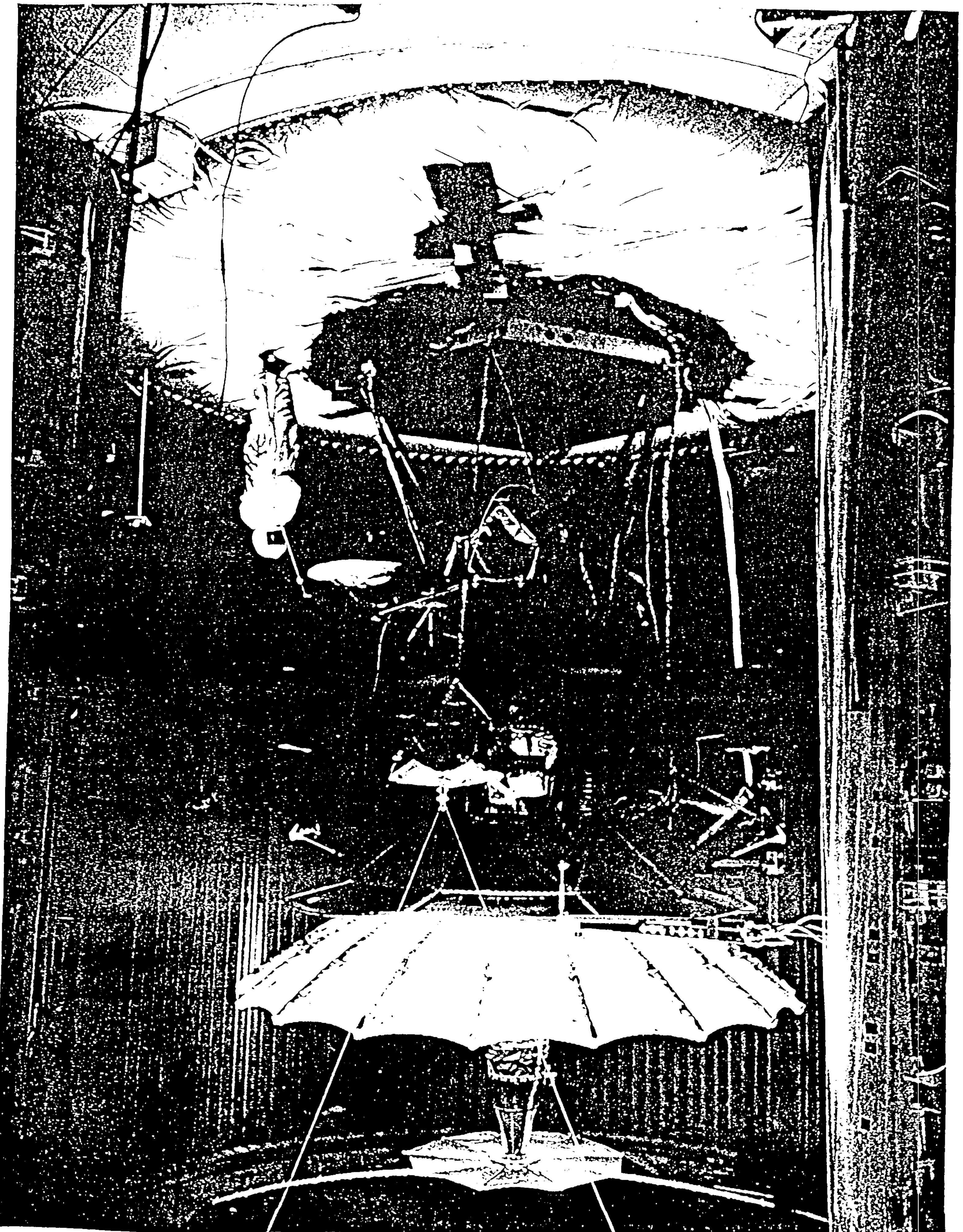
SUMMARY

- JPL is prototyping a mobile robot enabling remote response to incidents involving hazardous materials
- The end-user or customer - JPL HAZMAT Team - is directly involved in the project with input and advice from the JPL Safety Office
- Close contact has been maintained with manufacturer of original robot system

Robots are an effective tool for HAZMAT and other dangerous operations by enabling people to remotely, and therefore safely, perform tasks in hazardous environments.

SATELLITE TEST ASSISTANT ROBOT
PROBLEM

- Current JPL Solar Simulator Test Facility Capabilities are Limited To:
  - Direct Visual or Only Fixed-based and Crude TV inspection
  - Semi-Automated Solar Intensity Mapping
  - Constrained and Complex Thermal Mapping
  - Tedious and Time Consuming LN_2 Shroud Leak Detection
- These Limited Test Capabilities Can Cause Significant Test Interruption
- Any Test Interruption Is Costly and Time Consuming
  - Pump-Down/Return To Ambient Requires More Than 8 Hours
  - Under Test, 45 Tons of LN_2 Used Per Hour
  - Per Day Overhead Is About $50K
- The Quality Of Inspection And Mapping Capabilities Are Also Severely Limited



STAR VALIDATED IN THERMAL/VACUUM CHAMBER

- Sept. 1993:50 Hours Functional Testing ; Mobile, Real-Time, Video and Thermal Imaging
- Infrared Camera Remote Visualization of Cassini Hardware
- Operated with cold wall temperatures of -190 Centigrade and Six Ten Millionths Torr

ROBOT ASSISTED MICRO-SURGERY (RAMS)

- **Cooperative JPL (Engineering, Design** Fabrication) and MDS (**Requirements Definition and Field Test) Effort**
- **Master-Slave Dual-Arm Telemanipulation**
  - one cubic inch work volume’
  - feature sizes down to 20 microns
  - force reflection
- **Improved Surgical Outcomes Minimizing Tremor**

SSUES

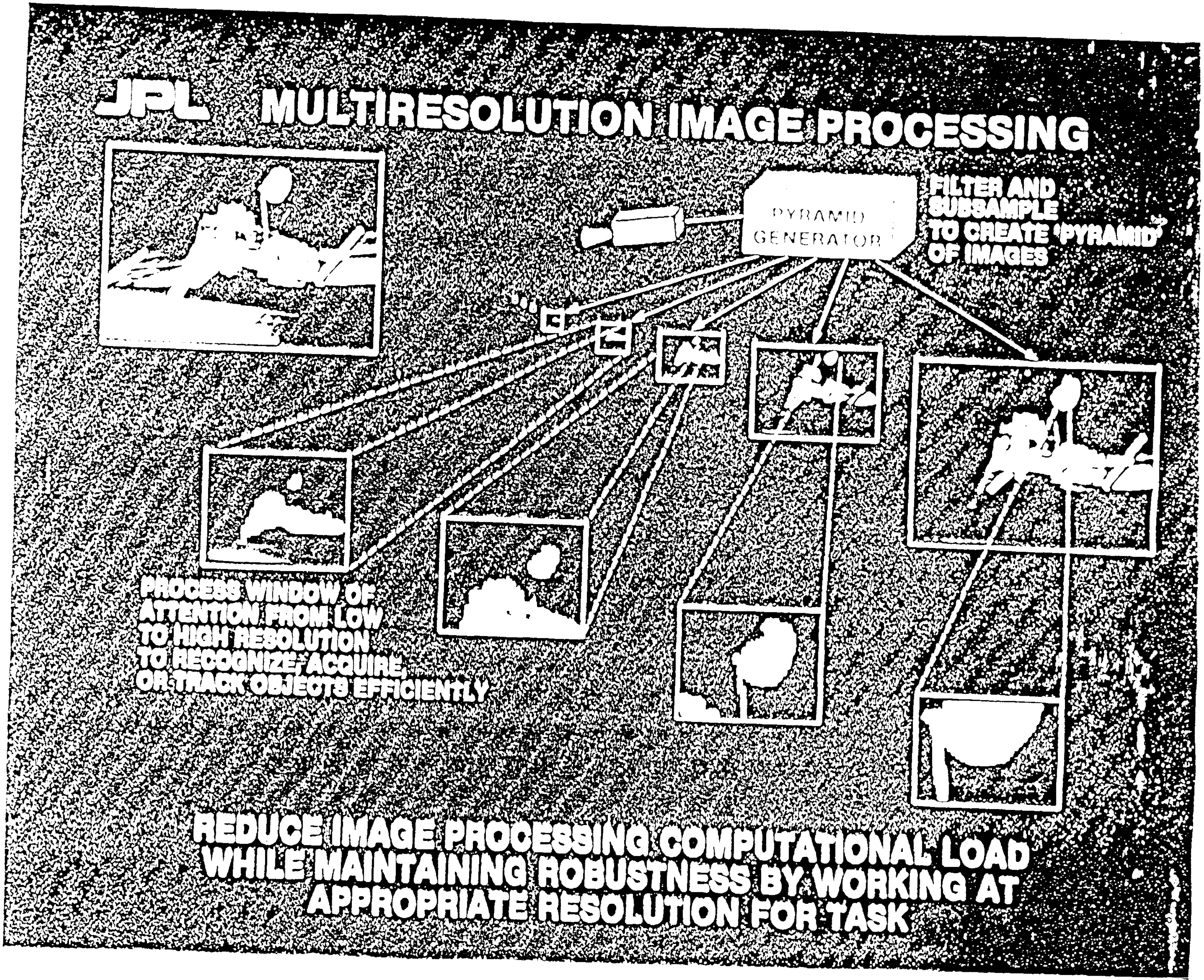
LEVEL OF SPATIAL KNOWLEDGE

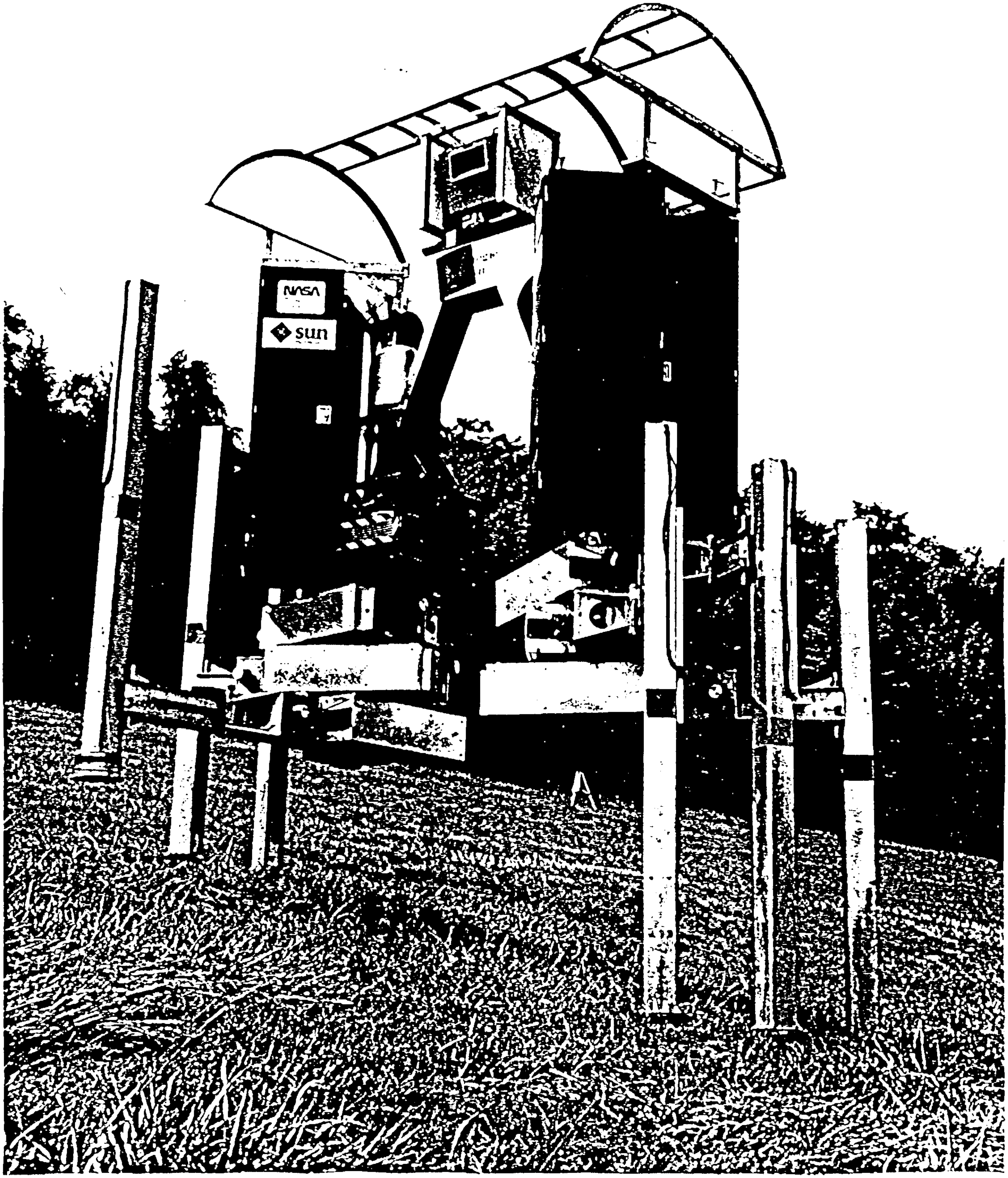
"MAGELLAN LEVEL"
- NAVIGATION DECISIONS BASED ON A KNOWN WORLD MAP
- EMPHASIS ON ROUTE PLANNING AND TRAVEL OPTIMIZATION
- USE OF A* LIKE ALGORITHM

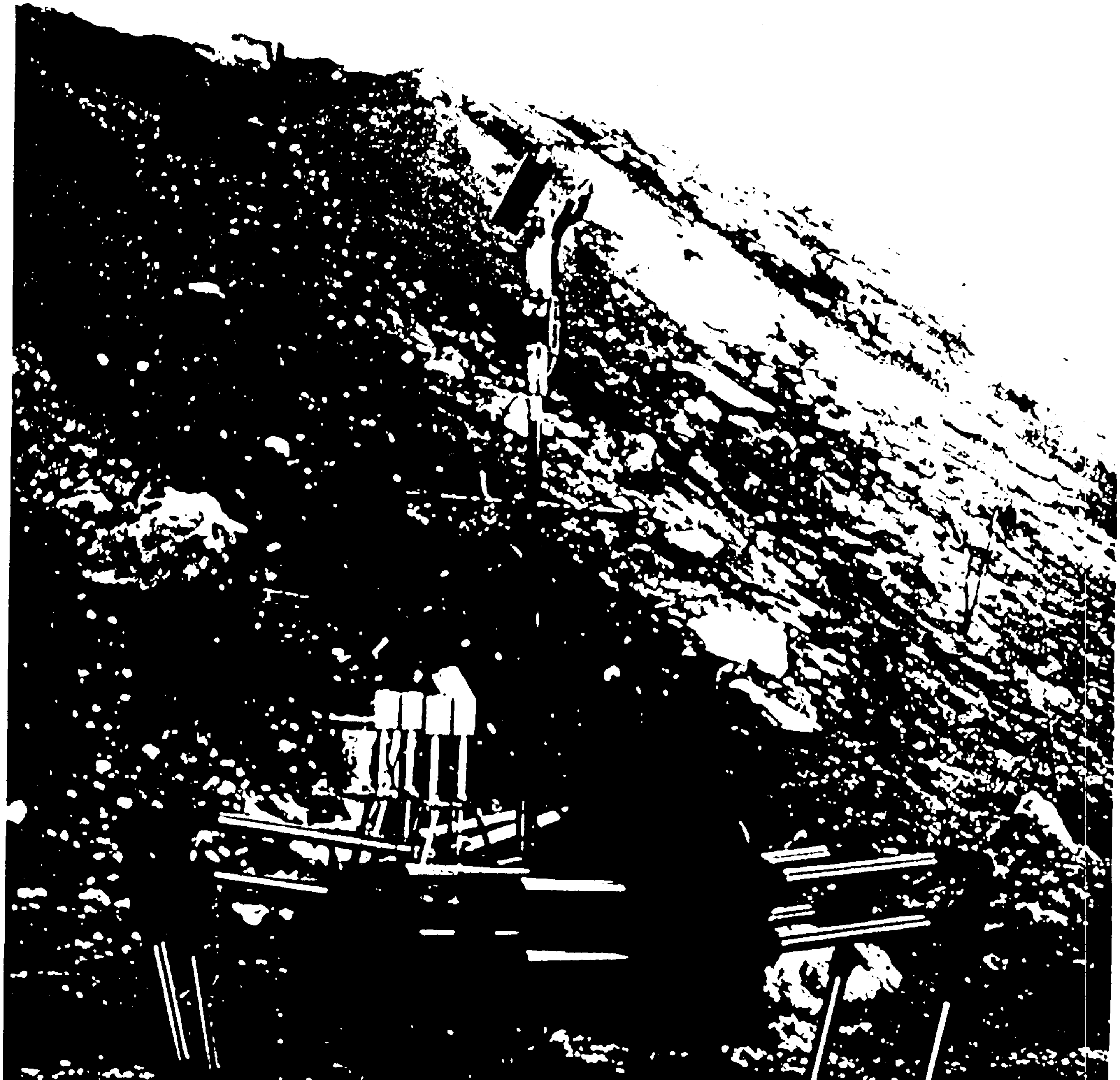
"COLUMBUS LEVEL"
- NAVIGATION TOWARD AN UNKNOWN AREA
- EMPHASIS ON OBSTACLE AVOIDANCE MAPPING, AND DISCOVERY

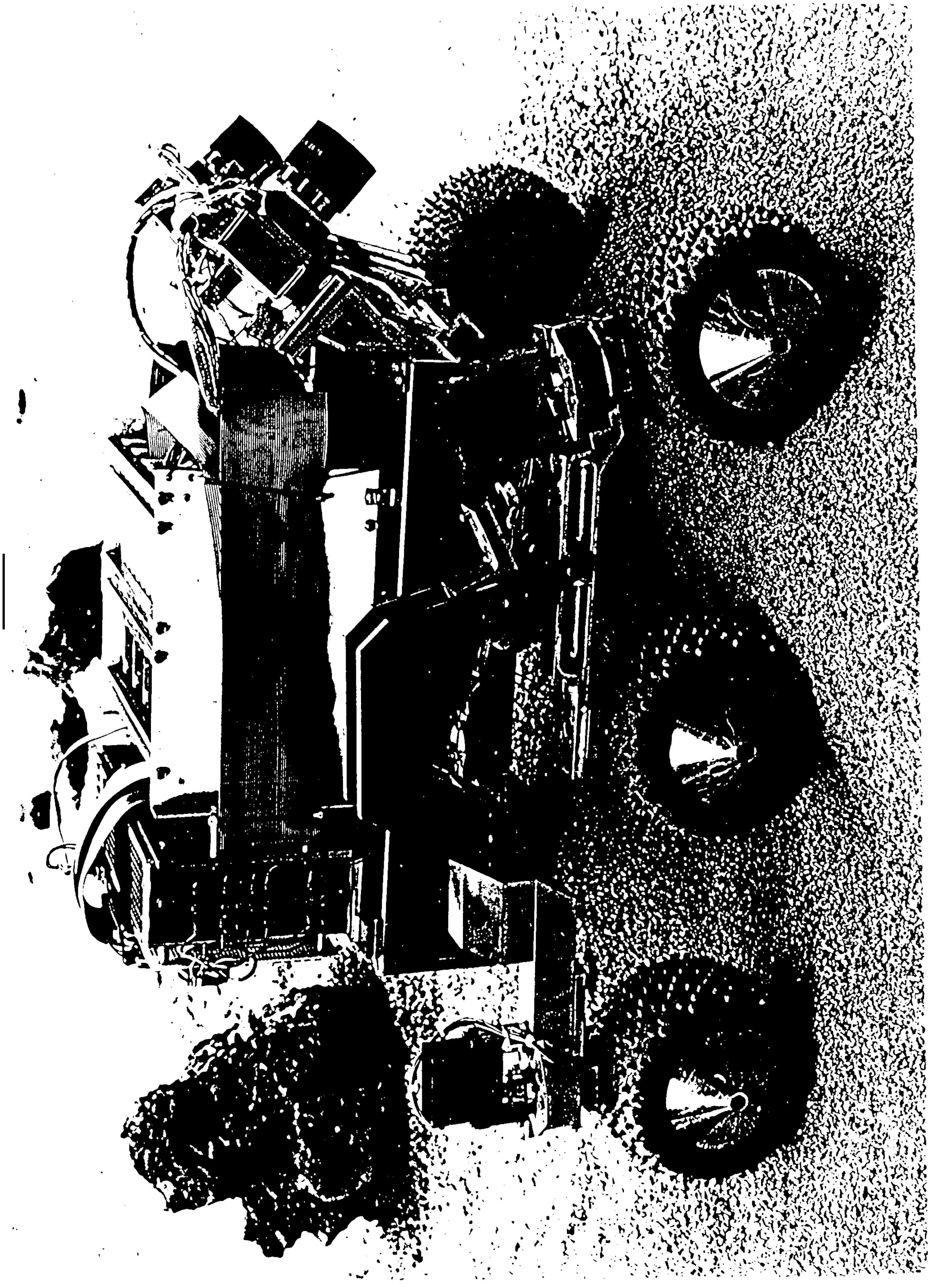
"ULYSSES LEVEL"
- NAVIGATION IN A CHANGING WORLD
- EMPHASIS ON REPLANNING AND WORLD MAP READADJUSTMENT


NASA
JPL


JPL
MULTIRESOLUTION IMAGE PROCESSING
PYRAMID GENERATOR
FILTER AND SUBSAMPLE TO CREATE 'PYRAMID' OF IMAGES
PROCESS WINDOW OF ATTENTION FROM LOW TO HIGH RESOLUTION TO RECOGNIZE, ACQUIRE, OR TRACK OBJECTS EFFICIENTLY
REDUCE IMAGE PROCESSING COMPUTATIONAL LOAD WHILE MAINTAINING ROBUSTNESS BY WORKING AT APPROPRIATE RESOLUTION FOR TASK


NASA
sun





Mars Pathfinder Rover Flight Experiment - Launch '96

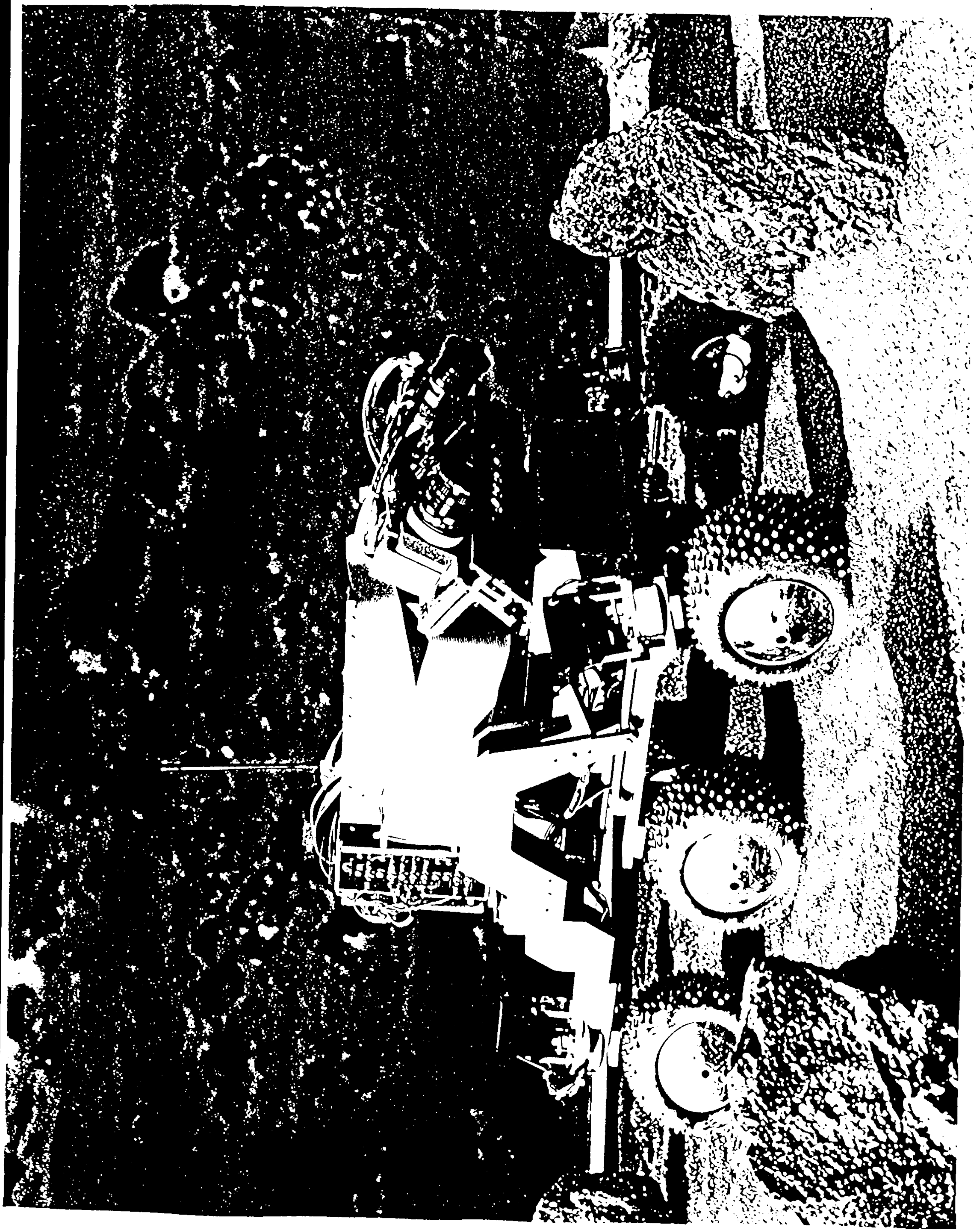
- Visit a few rocks in immediate vicinity of lander
- Place an alpha-proton-x-ray spectrometer near these rocks
  - no sampling or surface preparation
- Image lander
- Perform terrain and mobility experiments

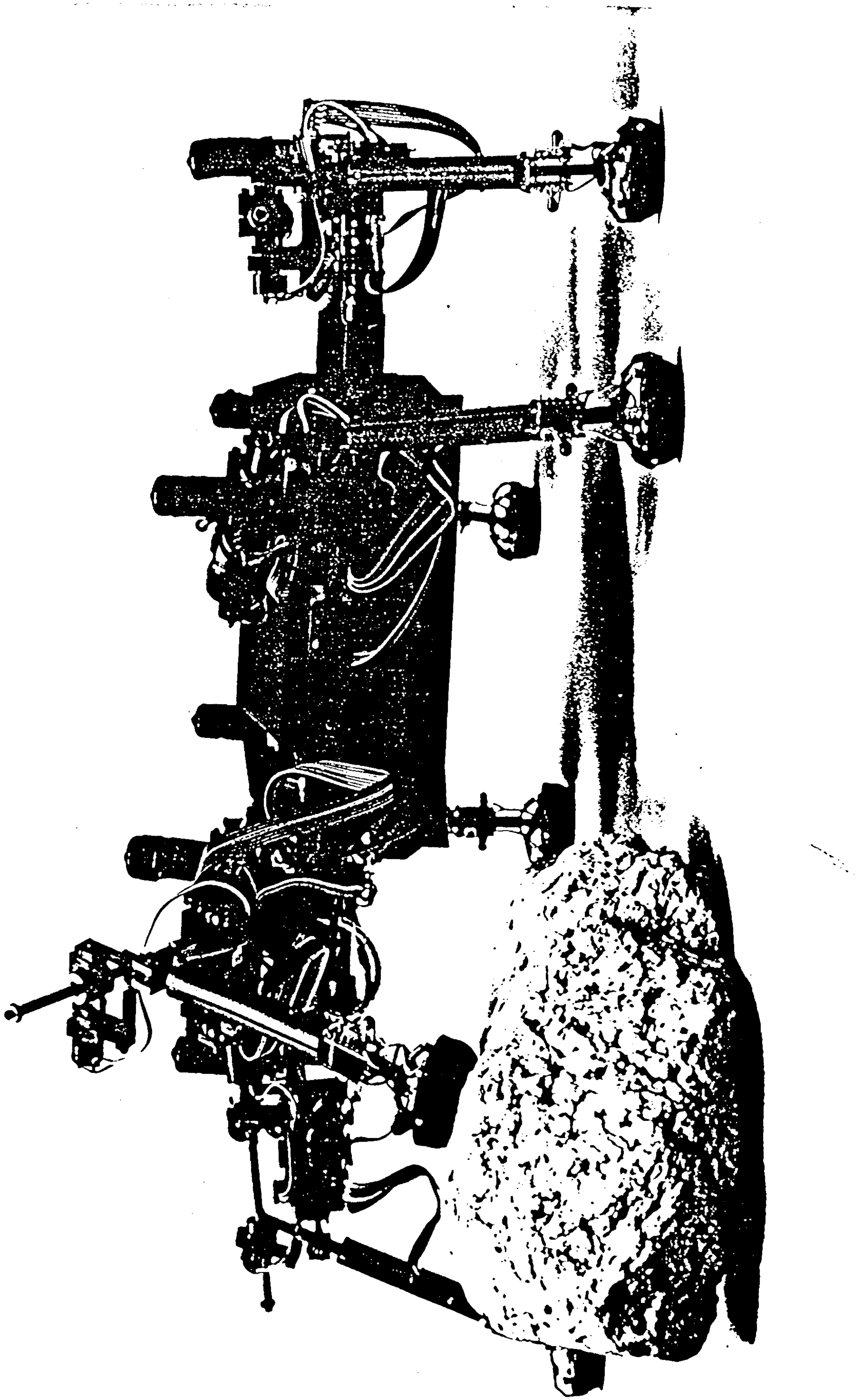
Rover Technology Program Goals - Near Term ('94-'96)

- **Enable next generation affordable rover missions to Mars (e.g. as part of Mars Surveyor Program)**
  - Reduction in landed mass over Pathfinder of at least a factor of 2
- **Higher science return**
  - short-to-mid range traverses in sparse (Viking 1) and cluttered (Viking II) rocky terrain from 10's of meters to 1 km from landing site
  - autonomously identifying, verifying, and mapping suitable science targets, retrieving fresh rock and other samples, accurately deploying instruments from small non-rigid bases
  - systematically characterize rover performance

Rover Technology Program - Longer Term (‘97 and Beyond)

- Larger scale exploration of Mars with a small number of longer range (>10 km) vehicles
- Move towards very long life (e.g. 10 years),





Program Milestones

- Reliable execution of multiple 50-100m traverses over moderate terrain **(Viking I) within sight of lander ('94)**
- **Fresh rock sampling mechanism** integrated on rover, autonomous science target **identification and mapping , 100m over-the-horizon and return to lander, Viking II terrain** ('95)
- Multiple sampling and instrument pointing/ **deployment modes, reliable 1 km traverse and return, in mixed terrain ('96)**
- **Miniaturized vehicle (5 kg) ('96)**

Key Rover Technologies

- **reliable navigation of dense obstacle fields (Viking II)**
- **characterization/identif ication of multiple** science targets/goals with high **liklihood**
- mechanization of miniature sampling **device and** control of device from non-rigid base
- sensing **for over-the-horizon navigation,** (geometric and non-geometric obstacles)
- error recovery and resource management
- strategies for site survey **and efficient use of** rover, lander, and ground locations
- **rover miniaturization**

ALGORITHMS VS. HEURISTICS

ALGORITHM - APPLIES TO PROCEDURES GUARANTEED TO SOLVE A PROBLEM

HEURISTIC - PLAUSIBLE BUT INCOMPLETE PROCEDURE

REFLEX VS. PLANNING

"HARD-WIRING" VS. INTERPRETATION OF BELIEFS/GOALS

COGNITIVE SCIENCE VS. ARTIFICAL INTELLIGENCE

PARALLEL THE OPERATION OF THE HUMAN BRAIN VS. MPROVING PERFORMANCE RE: SIMULATING INTELLIGENT BEHAVIOR

APPROPRIATE DEGREE OF ANTHROPOMORPHISM

SPECIAL PURPOSE END EFFECTORS VS. MULTIFINGERED HANDS

ALTERNATIVE COMPUTATIONAL APPROACHES

NEURAL NETWORKS:
AVOID EXPLICIT MODEL FORMULATION
TRAINING DONE OFF LINE
DIRECTLY INCORPORATES PARALLELISM

ISSUES: CONVERGENCE
SCALEUP
EXPLANATION

EXPERT SYSTEMS:
RULES EASY TO GENERATE AND EXTEND
VISIBLE AUDIT TRAIL

ISSUES: HEURISTIC
LACK OF RULE CONSISTENCY
BRITTLE; NO COMMON-SENSE KNOWLEDGE

MATHEMATICAL MODELS:
INCORPORATE KNOWN PHYSICS
LARGE EXPERIENCE BASE

ISSUES: MODELS NOT ALWAYS KNOWN
COMPUTATIONALLY DEMANDING

New Robotic Systems and Experiments to Fly Before 2000

- Canada
  - Space Station Remote Manipulator System (55 ‘; 7 DOF)
  - Special Purpose Dexterous Manipulator (two 7-DOF)
- Japan
  - Space Station Remote Manipulator Main Arm (6-DOF)
  - Small Fine Arm (6-DOF)
  - Free Flying Servicing Experiment (target and chase vehicles)
- Russia
  - Mars ’96: Marsokhod rover
- Germany
  - ROTEX

New Robotic Systems and Experiments to Fly Before 2000 (cont.)

- **United** States
  - Dexterous Orbiter Servicing System (7-DOF; Shuttle)
  - Ranger : dual arm free flyer
  - Charlotte: Science Payload Servicing
  - ROMPS: Robotic Operated Materials Processing System
  - Mars Pathfinder Rover
  - Lunar Rover (CMU-LunaCorp consortium)

PLANETARY ROVER NEAR-TERM CHALLENGES

- **Reliable navigation of dense obstacle fields (Viking II)**
- Real-time **perception and mapping of multiple** science targets/goals with high **liklihood**
- **Mechanization of miniature sampling device and control of device from non-rigid base**
- **Sensing for over-the horizon navigation (geometric and non-geometric obstacles)**
- **Error recovery and resource management**
- **Strategies for site survey and efficient use of** rover, lander, and ground **locations**
- **Rover miniaturization**

IN-SPACE SERVICING NEAR-TERM CHALLENGES

- Demonstrate automated operation **of** remote dexterous robots from the ground
- **Build libraries of robot skills and mechanisms for concatenization**
- **Implementation of sensory skins for obstacle** avoidance
- **Instrumented end effecters with improved dexterity**

ROBOT SYSTEMS GRAND CHALLENGES

- **ROBOT PLANETARY EXPLORERS WITH** COMMON SENSE (SURVEY SURFACES; **RECOGNIZE, RETRIEVE AND ANALYZE SCIENCE SAMPLES)**
  – autonomously confirm goal success
  – concatenate skills to achieve complex tasks
  – capability to learn and discover interesting things
- **MINIATURIZED ROBOTS WITH CAPABILITIES OF TODAY'S LARGE SYSTEMS**
  – core from a lightweight base
  – navigate large distances including very dense terrain, and beyond line of sight from lander

ROBOT SYSTEMS GRAND CHALLENGES (cont.)

- FLY HUMAN-LIKE ROBOT THAT CAN BY ITSELF RETRIEVE, SERVICE, AND REPAIR SATELLITES IN EARTH ORBIT
  - 3-D autonomous navigation
  - vision-guided rendezvous and docking
  - satellite grappling skills
- FLY A ROBOT THAT CAN INSPECT, DIAGNOSE, AND REPAIR ITSELF
  - automated inspection
  - real-time expert system diagnosis
  - dexterous manipulation
  - fault tolerance

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PRESENTATION AT MASSEY UNIVERSITY
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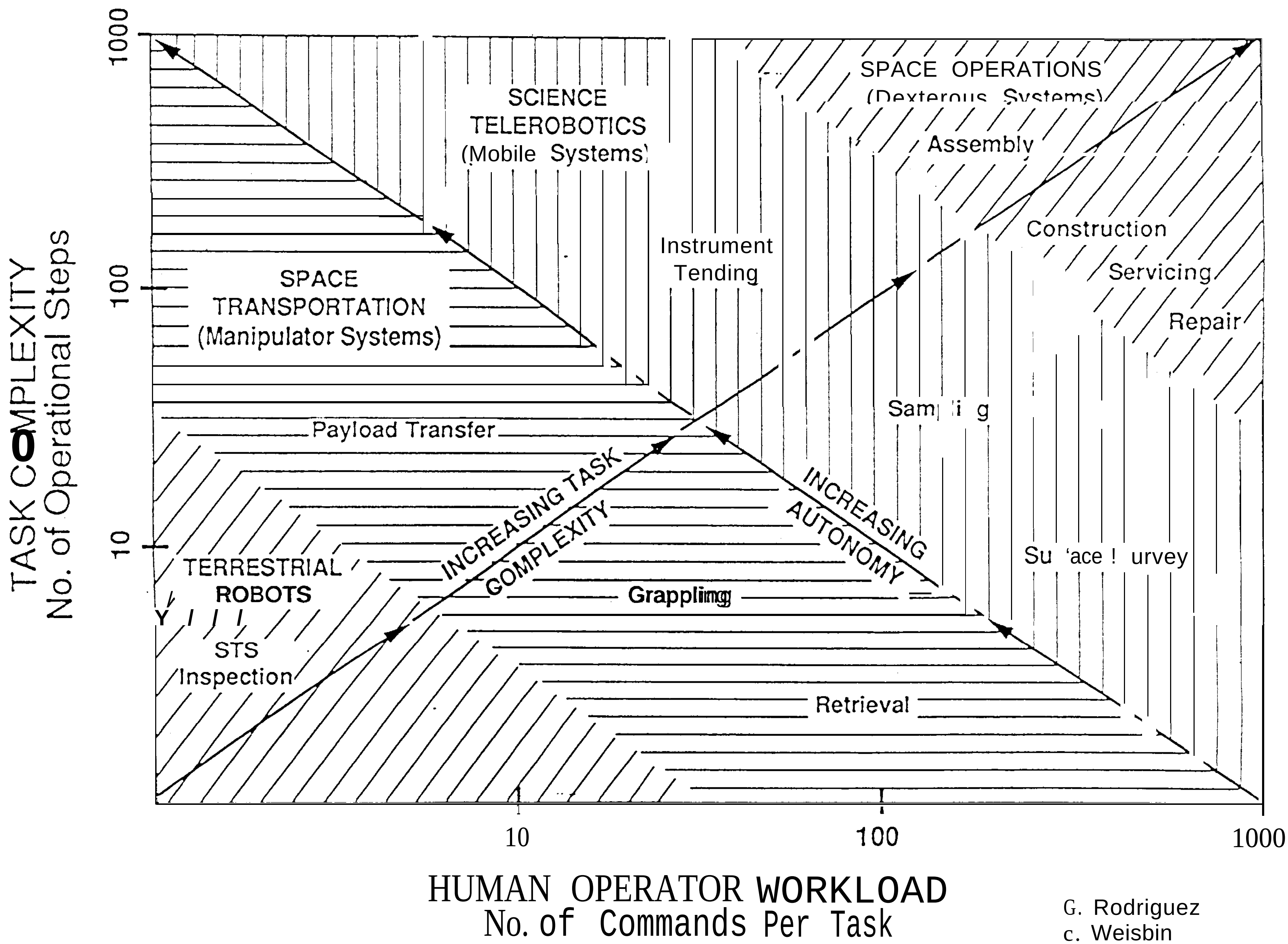

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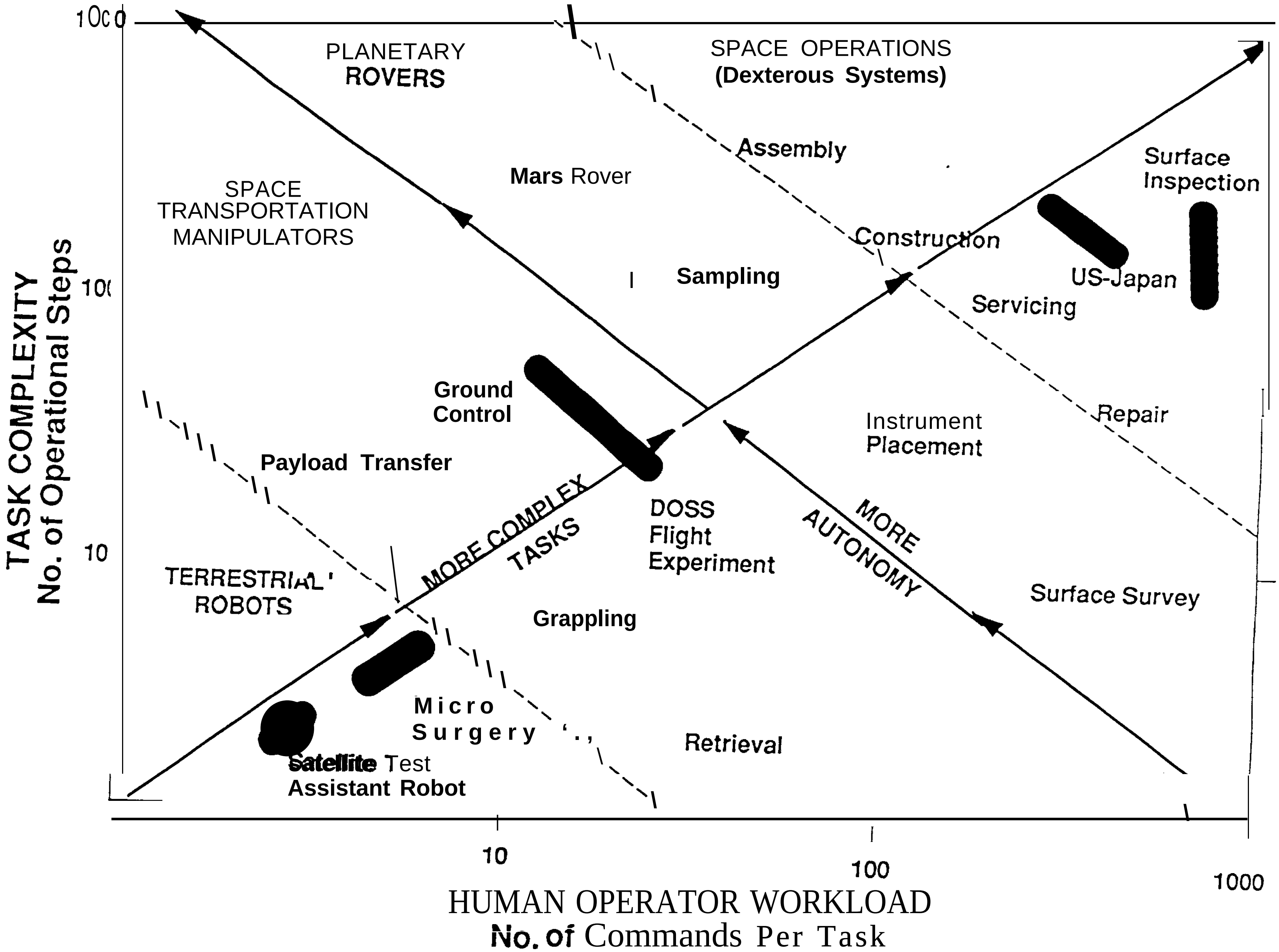

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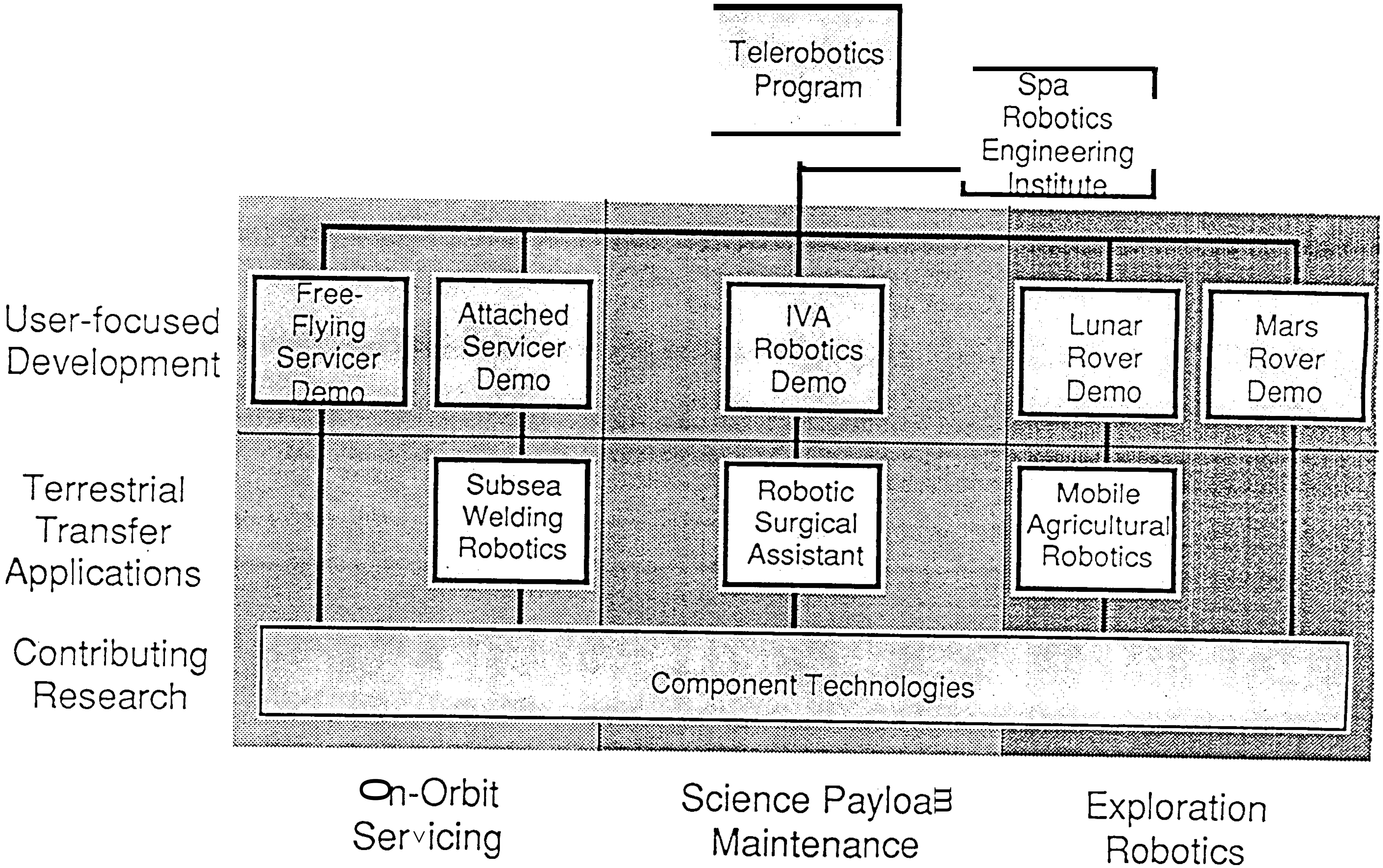

Telerobotics Program

TELEROBOTICS PROGRAM

- JSC
- KSC
- LaRC
- CMU
- U. Maryland
- MIT
- Stanford
- U. Texas

- Robotic Servicing Systems
- Robot Architectures
- Fault-Tolerant Mechanisms
- Students and Publications

- Earth orbiting missions
- Planetary surface operations

EMPHASIS OF PARTICIPANTS

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- **U. Md- Neutral Buoyancy; Free Flyer Expt.**
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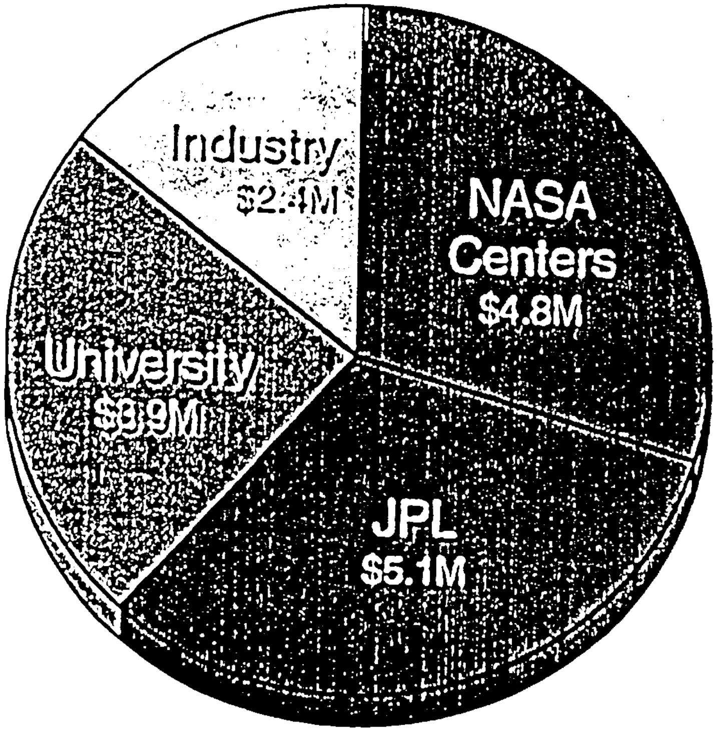
- **KSC- Shuttle Launch Processing**
- **ARC- Applied Virtual Reality Technology**

TR Research Funding Breakout



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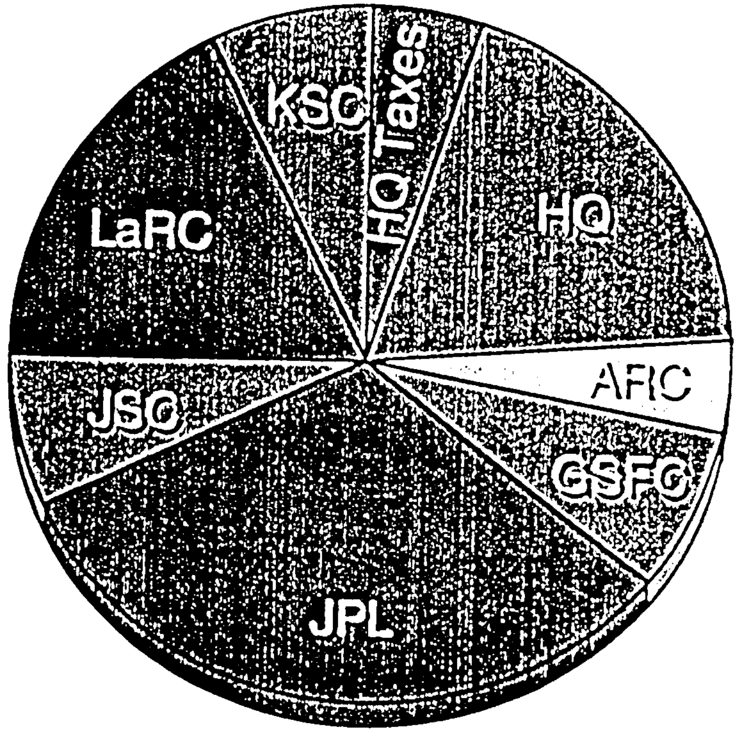

By **NASA** field center

Source: FY 1993 Telerobotics Program Plan.
Includes focussed program, base R&T
program, and forward-funded FY 1992 tasks

Telerobotics Program

UNIQUE NASA TELEROBOTICS TECHNOLOGY REQUIREMENTS

- NASA has unique needs in telerobotics technology
  - Time-delayed telerobotic systems
    (~8 sec. to earth-orbit, ~40 min. to Mars)
  - Mobile micro-rover and free-flying vehicles
  - Moveable-base and limber manipulators
  - Light and low-power flight telerobots
  - Low-mass, low-power advanced flight computing

- Related technology in other programs
  - Robot control architectures (NIST, RPI, etc.)
  - Natural terrain navigation (DARPA)
  - Maneuverable robots (Underwater Robotics)
  - Long-reach arms (Nuclear Waste Management)

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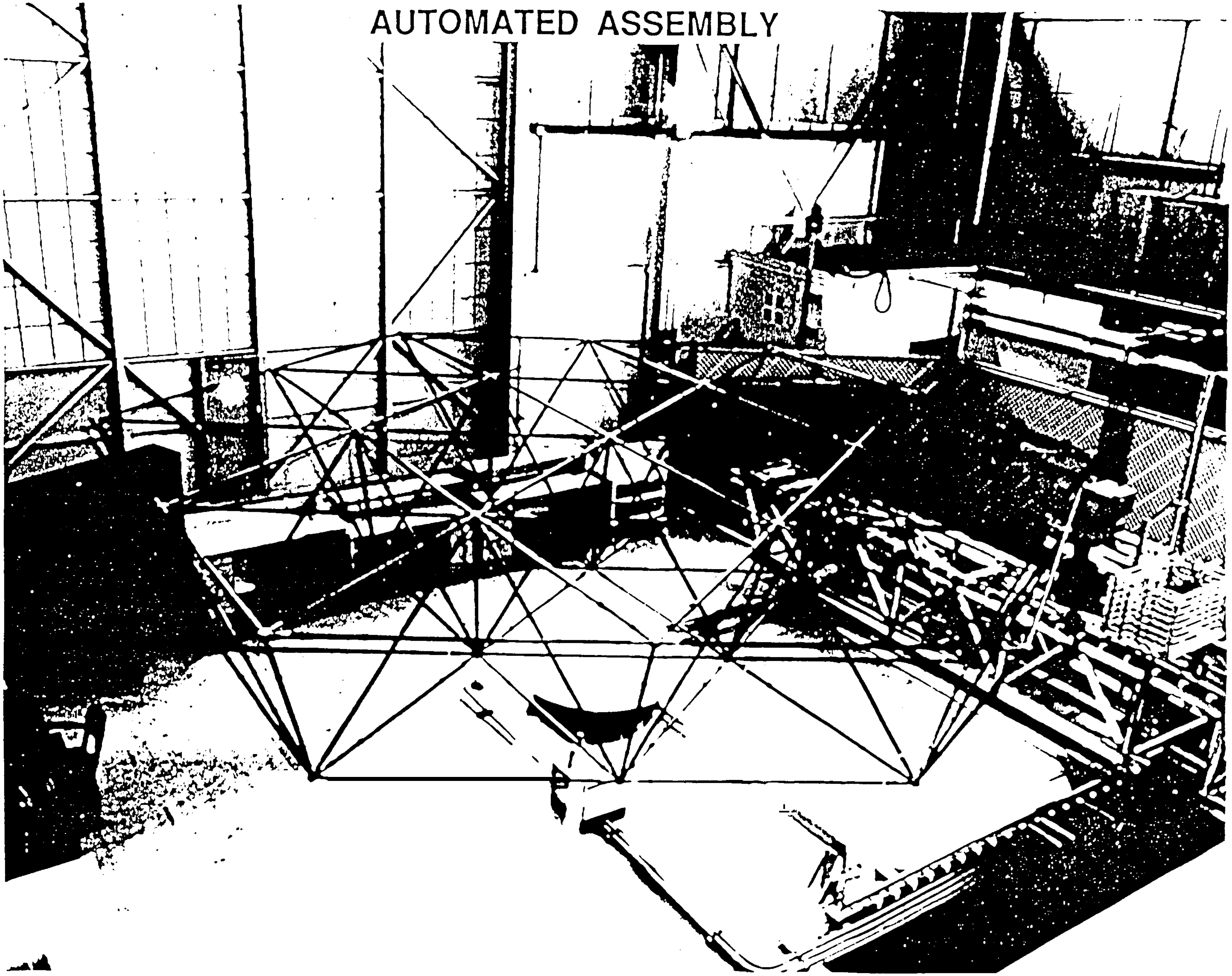
  - Embedded computer system software (DoD, DARPA)

AUTOMATED STRUCTURAL ASSEMBLY

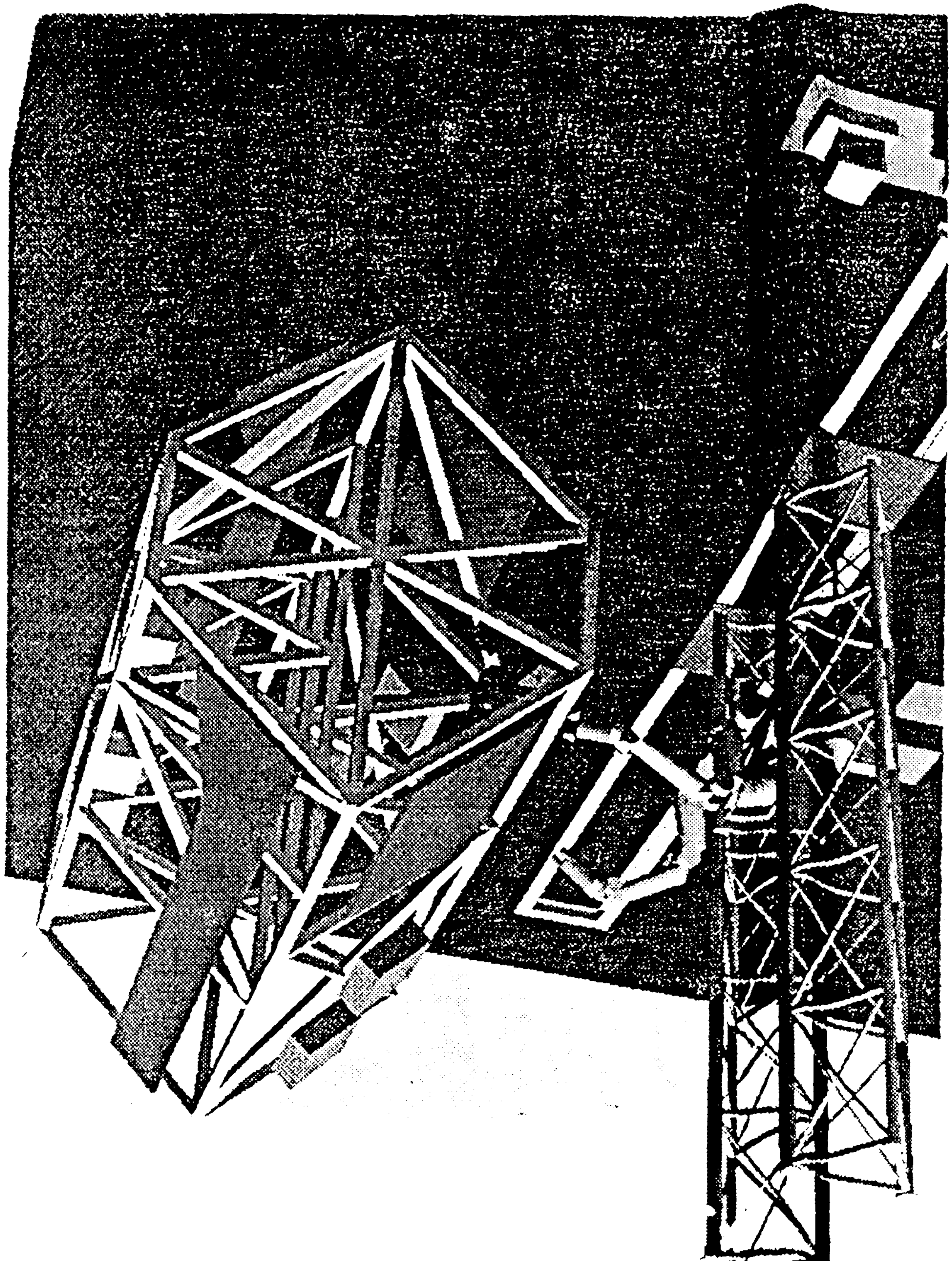
SHOWN:	• COMPLETED ASSEMBLY OF TRUSS STRUCTURE AND PANEL INSTALLATION
OBJECTIVE:	• DEVELOP AUTOMATED ASSEMBLY METHODS FOR LARGE SPACE STRUCTURES
ACCOMPLISHMENTS:	• SUCCESSFUL ASSEMBLY OF A 102-MEMBER STRUCTURE AND INSTALLATION OF 12 PLANAR PANELS IN “SUPERVISED AUTONOMY" MODE WITH MINIMUM OF MANUAL INTERVENTION
	• AUTOMATIC EXCHANGE OF ASSEMBLY MECHANISMS
	• MACHINE VISION-BASED GUIDANCE
	• EXPERT SYSTEM-BASED ASSEMBLY EXECUTIVE PROGRAM
BENEFITS:	• FEASIBILITY OF AUTOMATED ASSEMBLY OF SPACE STRUCTURES
	• FOUNDATION FOR DEVELOPMENT OF TELEROBOTIC ASSEMBLY METHODS FOR NONPLANAR STRUCTURES
APPLICABLE MISSIONS:	• LARGE ANTENNA
	• AEROBRAKE ASSEMBLY
	• SOLAR POWER COLLECTORS
	• LARGE PLATFORMS BEYOND SHUTTLE ALTITUDES
	• LUNAR/PLANETARY SURFACE CONSTRUCTION

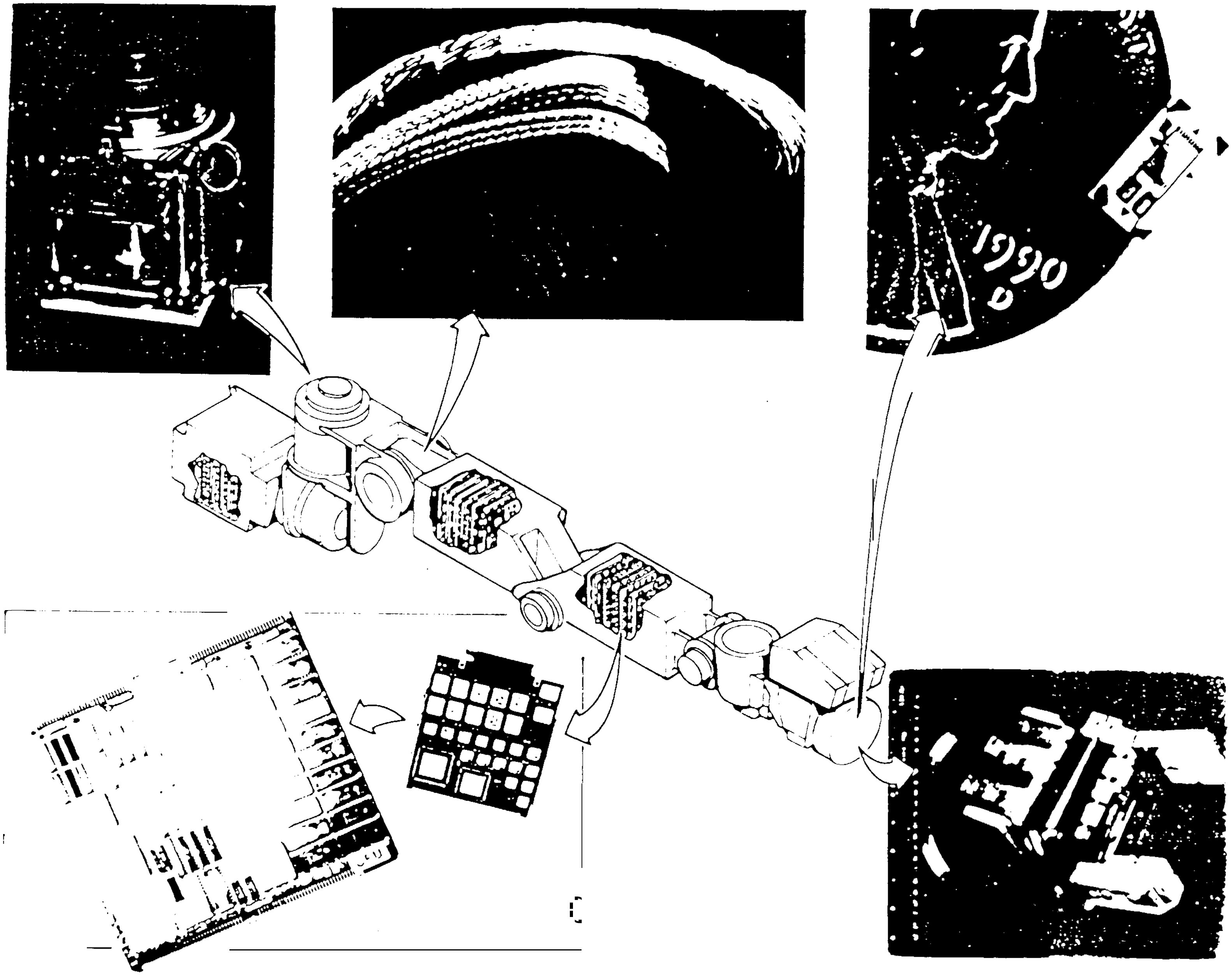
AUTOMATED ASSEMBLY



Automated Robotic Maintenance for Space Station

- 1. Emulate current SPDM operational and control characteristics using the 7-DOF Robotics Research manipulators.
- 2. Perform candidate SSF/ORU servicing tasks on a full scale Pre-Integrated Truss (PIT) mockup
- 3. Modifications to permit remote/ground control of the ARMSS workstation are in work
- 4. Tech transfer for capaciflector, flat target, operator control station, surface inspection, and hexeye.





TELEROBOTICS INSPECTION (JPL)

JUSTIFICATION

- Several studies have indicated that inspection will be an important activity for Space Station Freedom

  - NASA/JSC Final Report, Space Station Freedom External Maintenance Task Team, W.F. Fisher and C.R. Price., July 1990

  - SAIC Blue Panel Report, June 12,1990

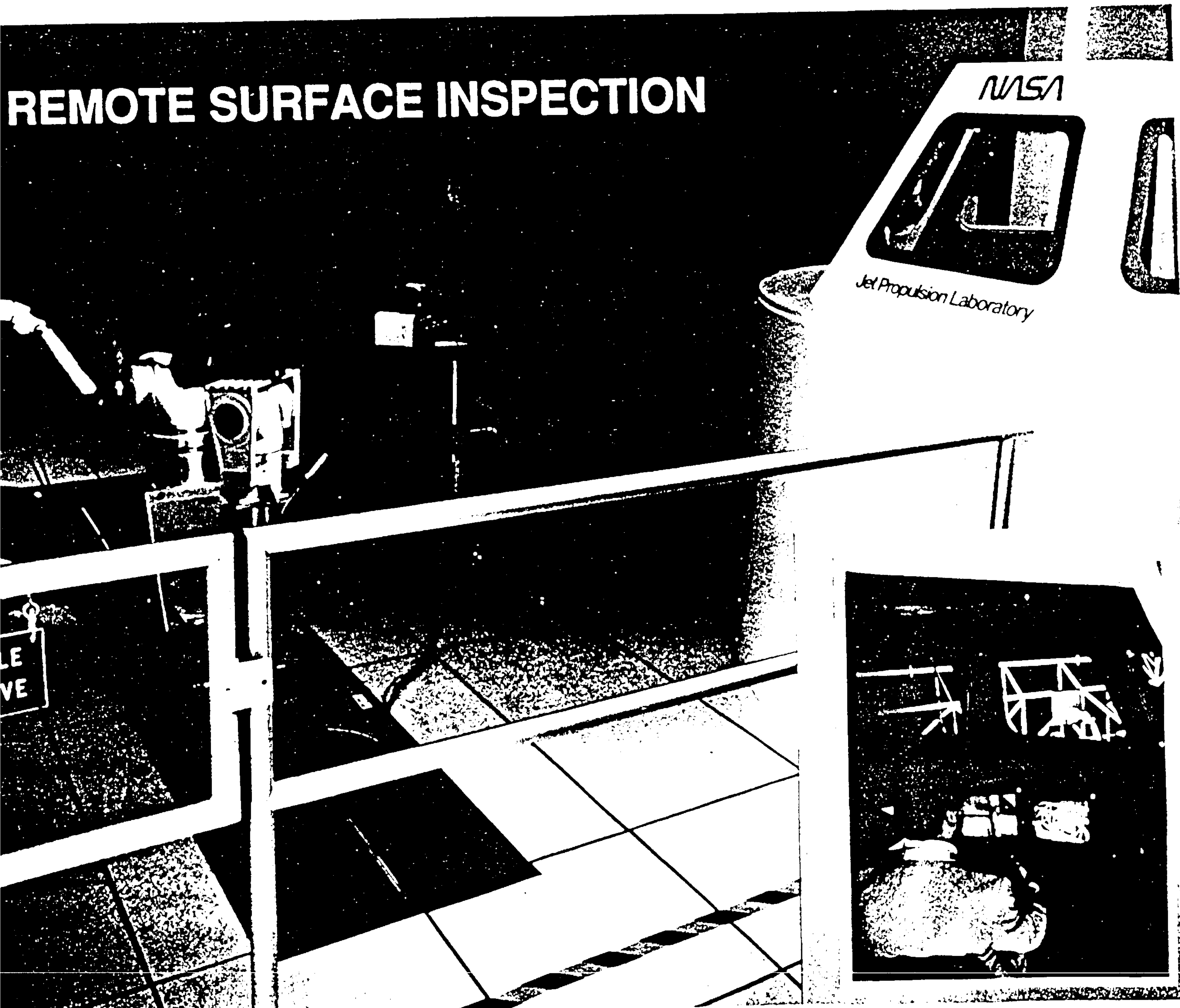
  - NASA Headquarters Report: Office of Space Station, Space Station Freedom Automation and Robotics: An Assessment of the Potential for increased Productivity, December 1989

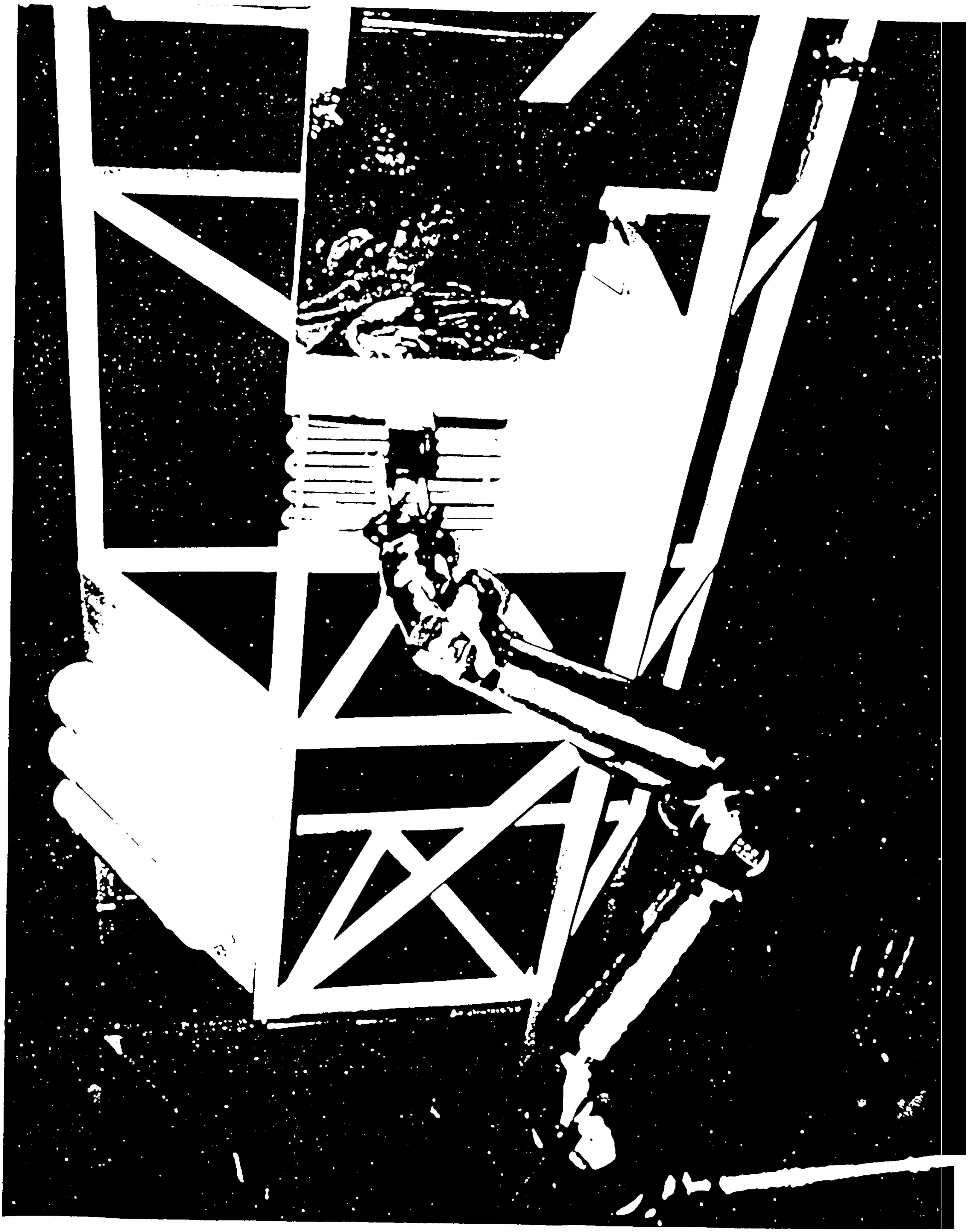
- Use of telerobotics can reduce astronaut EVA time

- Database from this task will provide actual experimental data for more realistic estimates for the SSF inspection tasks

- This task will also show technology readiness and identify what new technologies are required for inspection tasks

REMOTE SURFACE INSPECTION





REMOTE SURFACE INSPECTION

AUTOMATED FLAW DETECTION

OBJECTIVE: Detection of flaws for simple but time consuming inspections tasks

GENERAL APPROACH: Detection of changes between "before" and "after" images of a scene

TECHNICAL ISSUES:

- Earth orbit ambient light variations for "before" and "after" images

- Misregistration between the "before" and "after" images due to camera positioning repeatability which causes large differences in high contrast regions

TECHNICAL APPROACH:

- Subtract image of ambient lit surface from one lit by controlled lights and improve the results by averaging over many images

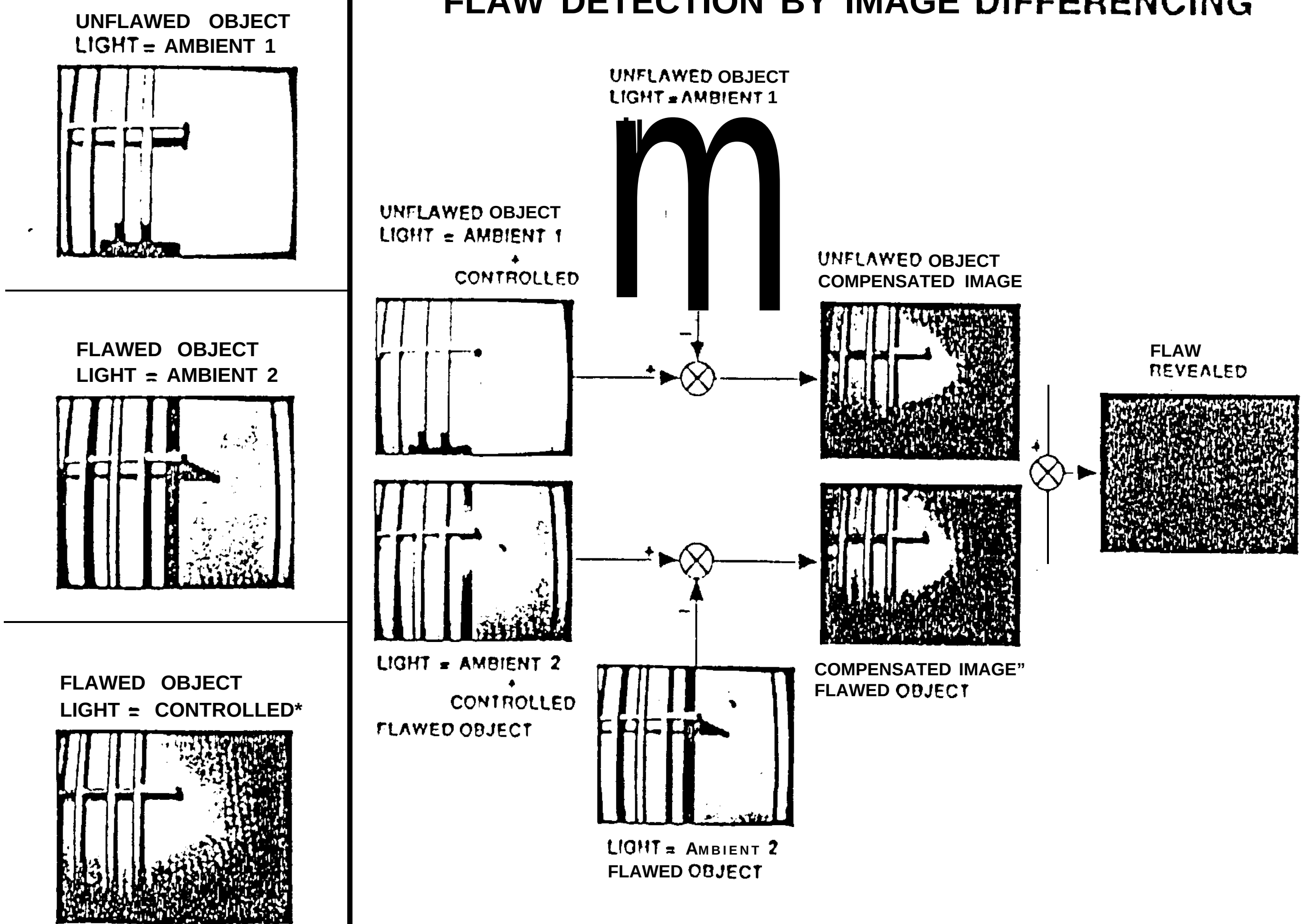
- Develop estimation approach to correct for camera repositioning error

JPL

REMOTE SURFACE INSPECTION

REMOTE SENSOR AND PROCESSOR MODULE

FLAW DETECTION BY IMAGE DIFFERENCING

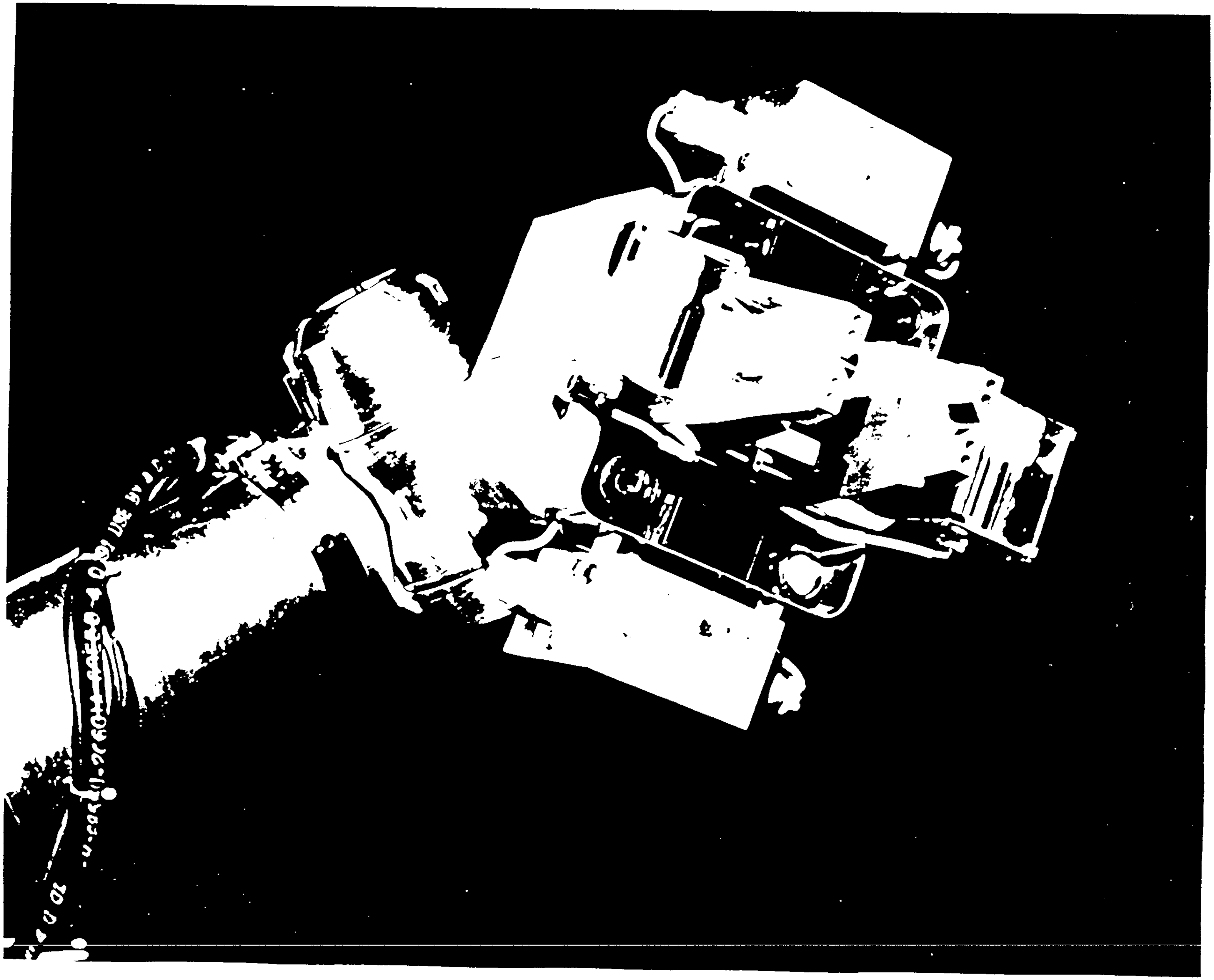


*COMPENSATED IMAGE MATCHES THAT OBTAINED BY USING CONTROLLED LIGHTS ALONE

CONFIGURATION CONTROL FOR REDUNDANT ROBOTS

- A new and powerful control methodology for redundant robots has been developed
- Redundancy is utilized to accomplish any user-defined "additional task," while the robot is executing the "basic task" of desired end-effecter motion
- Diverse additional tasks can be specified within a broad framework, such as:
  - posture control
  - optimization
  - singularity avoidance
  - obstacle avoidance
  - joint limit avoidance
- Control schemes are robust, computationally fast, and suitable for real-time implementation in two modes:
  - Kinematic control as a generalized inverse kinematics transformation
  - Dynamic control within model-based or adaptive control frameworks
- Provides a unified framework for shared control of redundant robots, where operator commands 6 DOF end-effecter motion and autonomous system resolves the redundancy
- Control schemes have been validated experimentally on 3 planar links of PUMA and verified by extensive simulations on the 7 DOF Robotics Research arm

MULTI-SENSOR BASED INSPECTION



Surface Inspection

- 1. Simulated **solar lighting**
- **2. Continuous motion inspection**
- 3. **Flaw detection to 3-5 mm**
- **4. Automatic cataloging of flaws in data base**
- **5. Benchmarking detection capability**
- **6. Dexterous 7-DOF manipulator motion**
- **7. Stereo viewing and flyover capability**
- **8. Multi-sensors: visual, pyrometer, gas,** proximity, force, **eddy current**
- 9. Snake-like end effecter

RATIONALE

- DEXTERITY IN MANIPULATION RESIDES IN THE CAPABILITIES OF END EFFECTORS

- CURRENT DEXTEROUS SPACE MANIPULATION TASKS ARE MAN RATED

- THE NEED FOR MAN-EQUIVALENT MECHANICAL HAND CAPABILITIES THEREFORE EXISTS

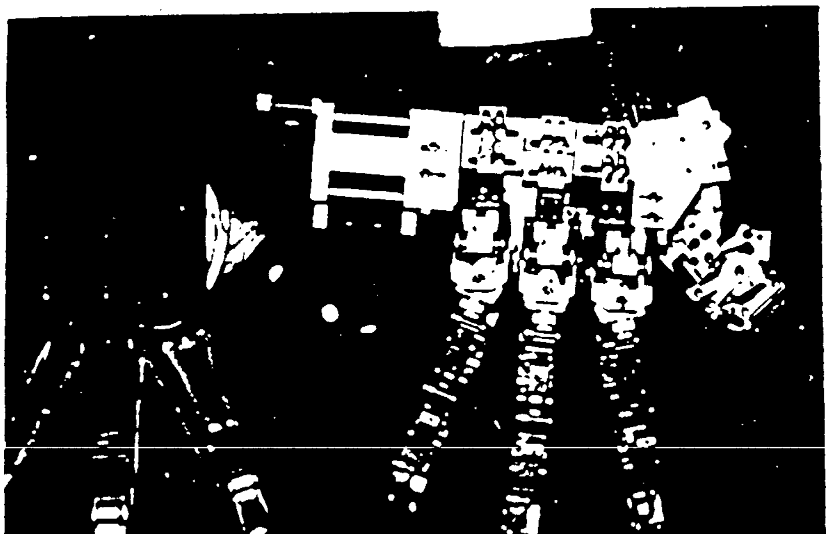
- ANTHROPOMORPHIC TELEMANIPULATOR WILL ENABLE MAN-EQUIVALENT, DEXTEROUS, DUAL ARM-HAND MANIPULATIONS

- ANTHROPOMORPHIC TELEMANIPULATION SOLVES CONTROL PROBLEM BY EMPLOYING THE OPERATOR TO GUIDE THE MANIPULATOR IN A NATURAL WAY

TELEPRESENCE: EXOSKELETON TELEMANIPULATION

EVA GLOVE

EXOSKELETON MASTER "GLOVE HAND" AND SLAVE HAND



THE EXOSKELETON ALTERNATIVE

- QUESTION: HOW FAR CAN THE EXOSKELETON ALTERNATIVE TRULY PERFORM THE EVA-GLOVE RATED MANIPULATIVE ACTIVITIES WITHOUT CHANGING EVA TOOLS/ PERIPHERALS OR WITHOUT ADDING NEW ONES TO THE EXISTING REPERTOIRE? (155 TOOLS AS OF 1985)

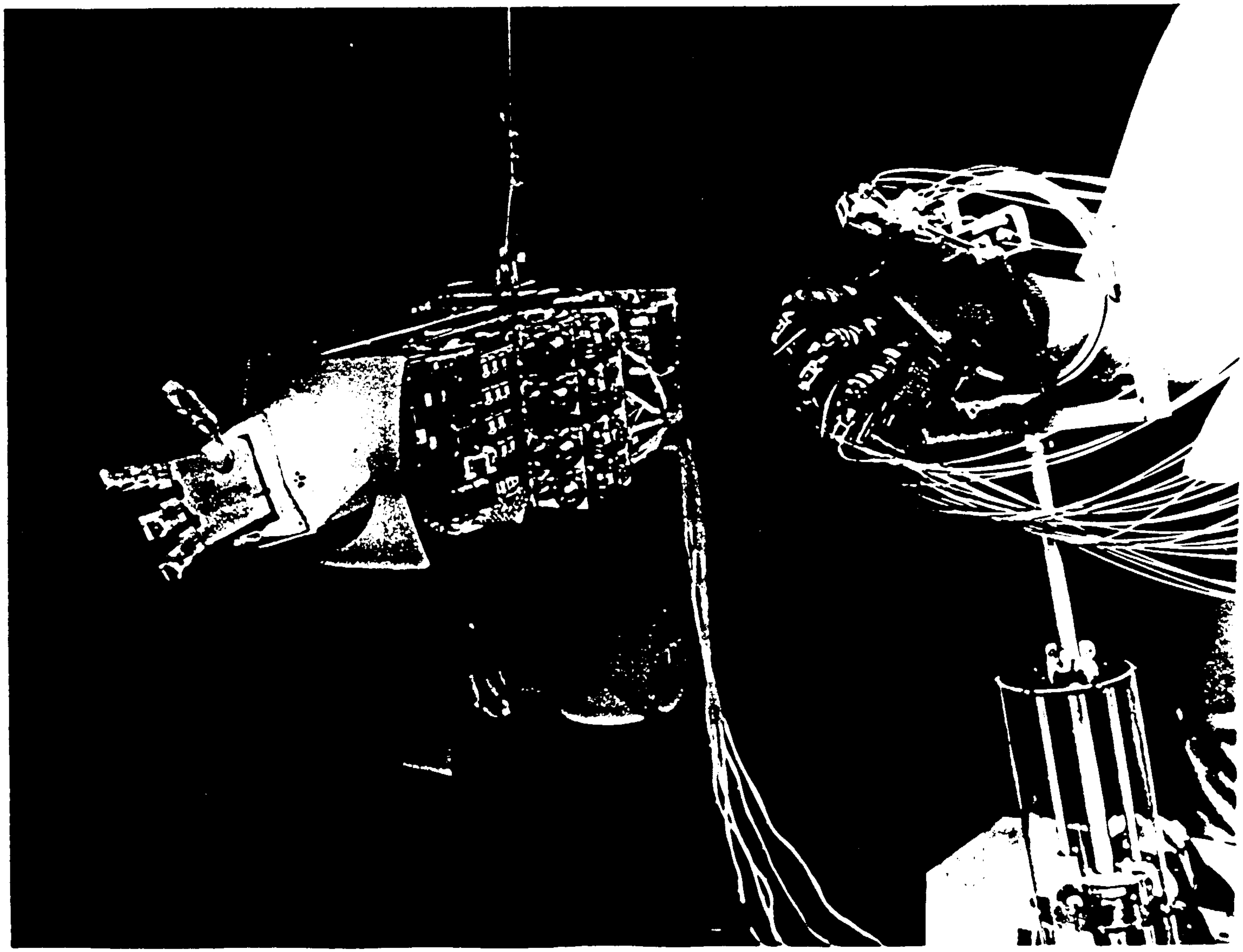
- ANSWER: CARRY OUT EXOSKELETON EXPERIMENTS WITH REALISTIC EVA TASKS, IN COOPERATION WITH INTERESTED NASA CENTERS' PERSONNEL

[INFORMATION SOURCE FOR EVA TOOLS/TASKS TEST CANDIDATES: NASA DOCUMENT "EVA CATALOG, TOOLS AND EQUIPMENT", JSC-20466, NOV. 1985.]

JPL

TELEPRESENCE WITH ANTHROPOMORPHIC EXOSKELETON SYSTEM

FORCE-REFLECTING MASTER GLOVE AND REPLICA SLAVE HAND IN TERMINUS CONTROL CONFIGURATION



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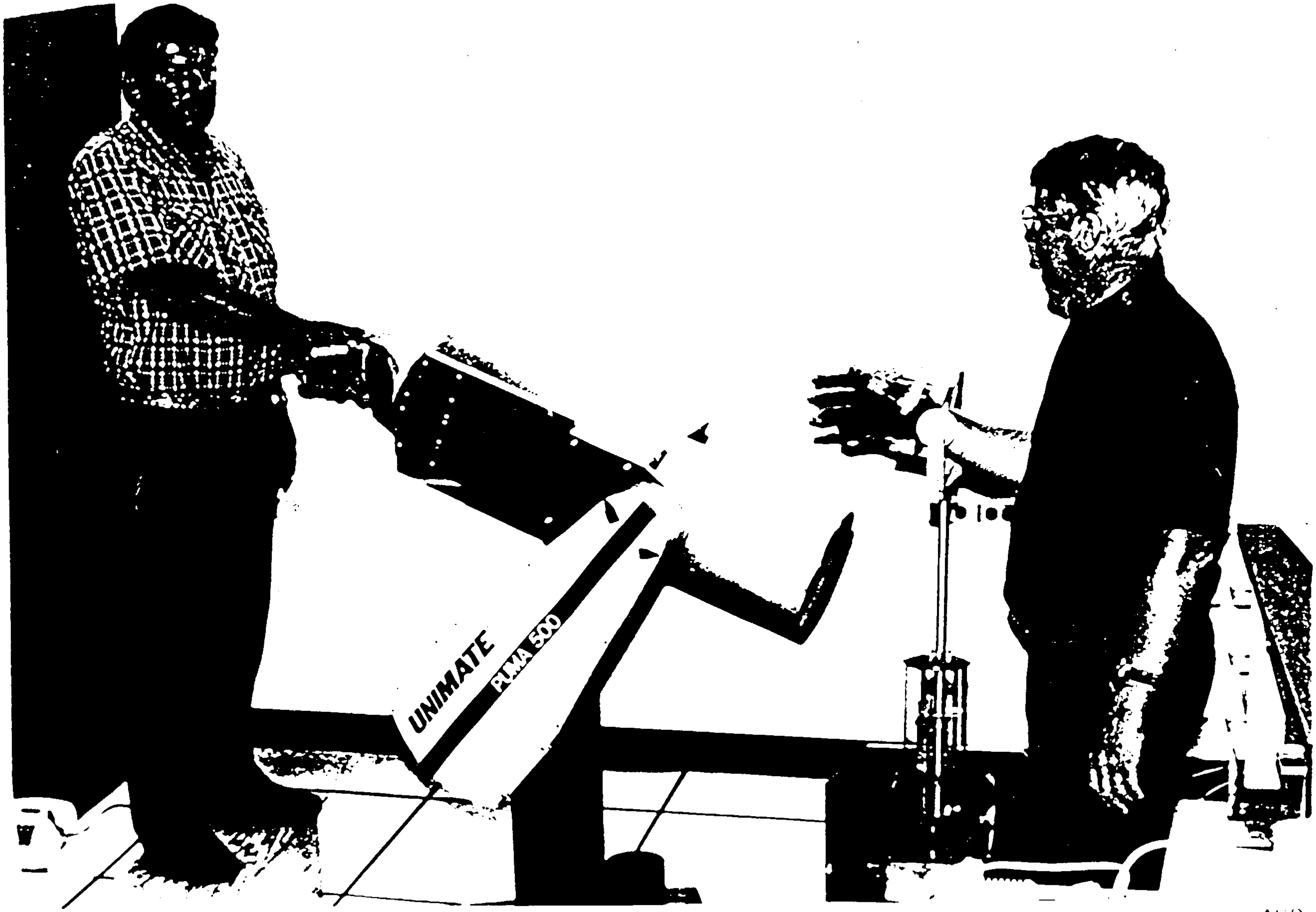
TELEPRESENCE

FORCE-REFLECTING MASTER GLOVE AND REPLICA SLAVE HAND IN TERMINUS CONTROL CONFIGURATION



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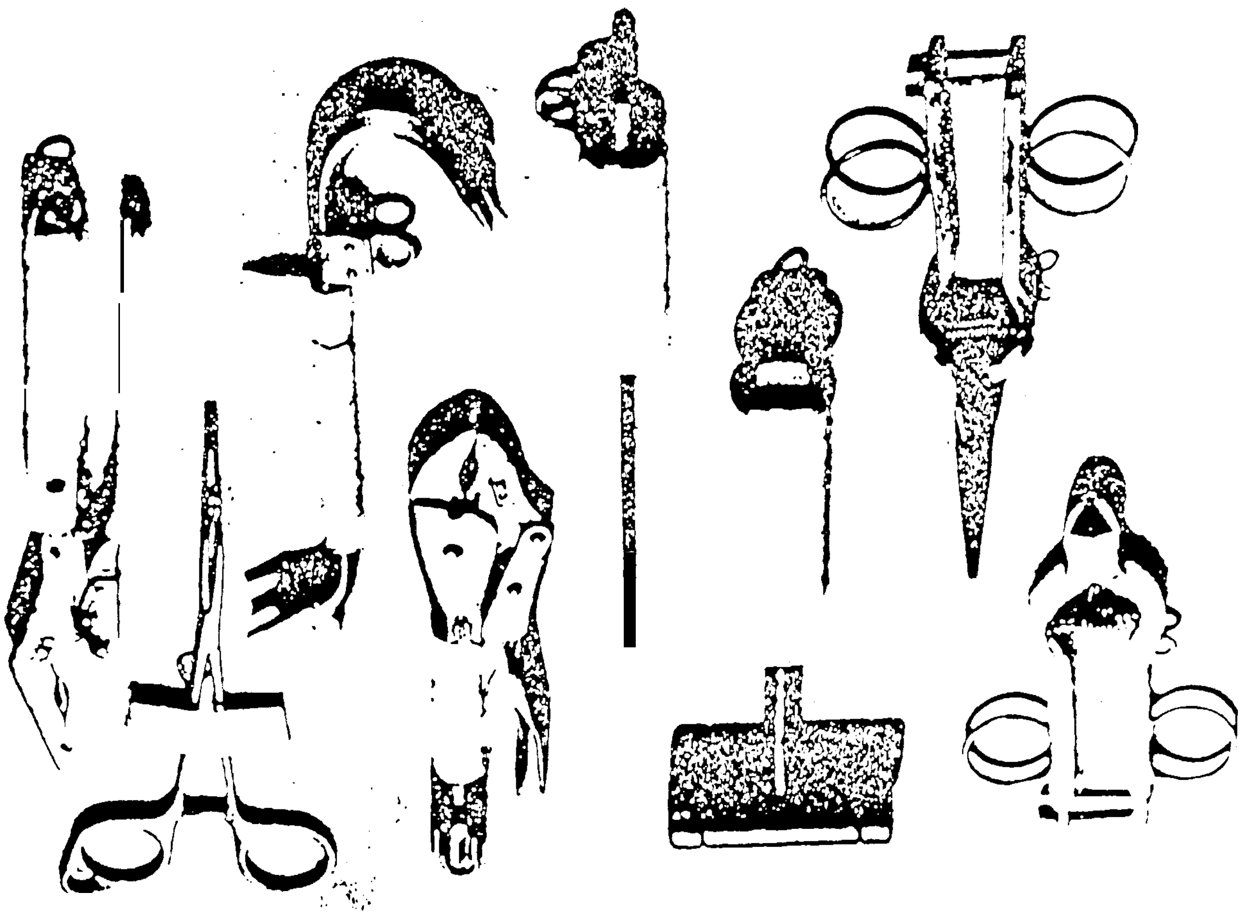
CANDIDATES FOR IEXOSKELETON TOOL HANDLING TASKS

"EVA" JAM REMOVAL TOOLS



(FROM: NASA DOCUMENT "STS, EVA DESCRIPTION AND DESIGN criteria-', JSC-10615, MAY 1983, p.19)

ADVANCED TELEOPERATION

DESCRIPTION

- DEVELOP COMPUTER GRAPHICS SYSTEM FOR CALIBRATION AND PREDICTED IMAGE OVERLAY OVER ACTUAL TV VIEWS OF TASK SCENES
- DEVELOP GROUND OPERATOR CONTROL SYSTEM FOR REMOTE ROBOT ARMS IN SPACE UNDER SEVERAL SECONDS COMMUNICATION TIME DELAY

NASA NEEDS/SIGNIFICANCE

- GROUND OPERATOR CONTROL OF SPACE TELEROBOTIC DEVICES REDUCE COST OF EVA AND IVA ACTIVITIES AND ENABLE MANIPULATION TASKS FOR WHICH EVA OR IVA RESOURCES ARE NOT AVAILABLE

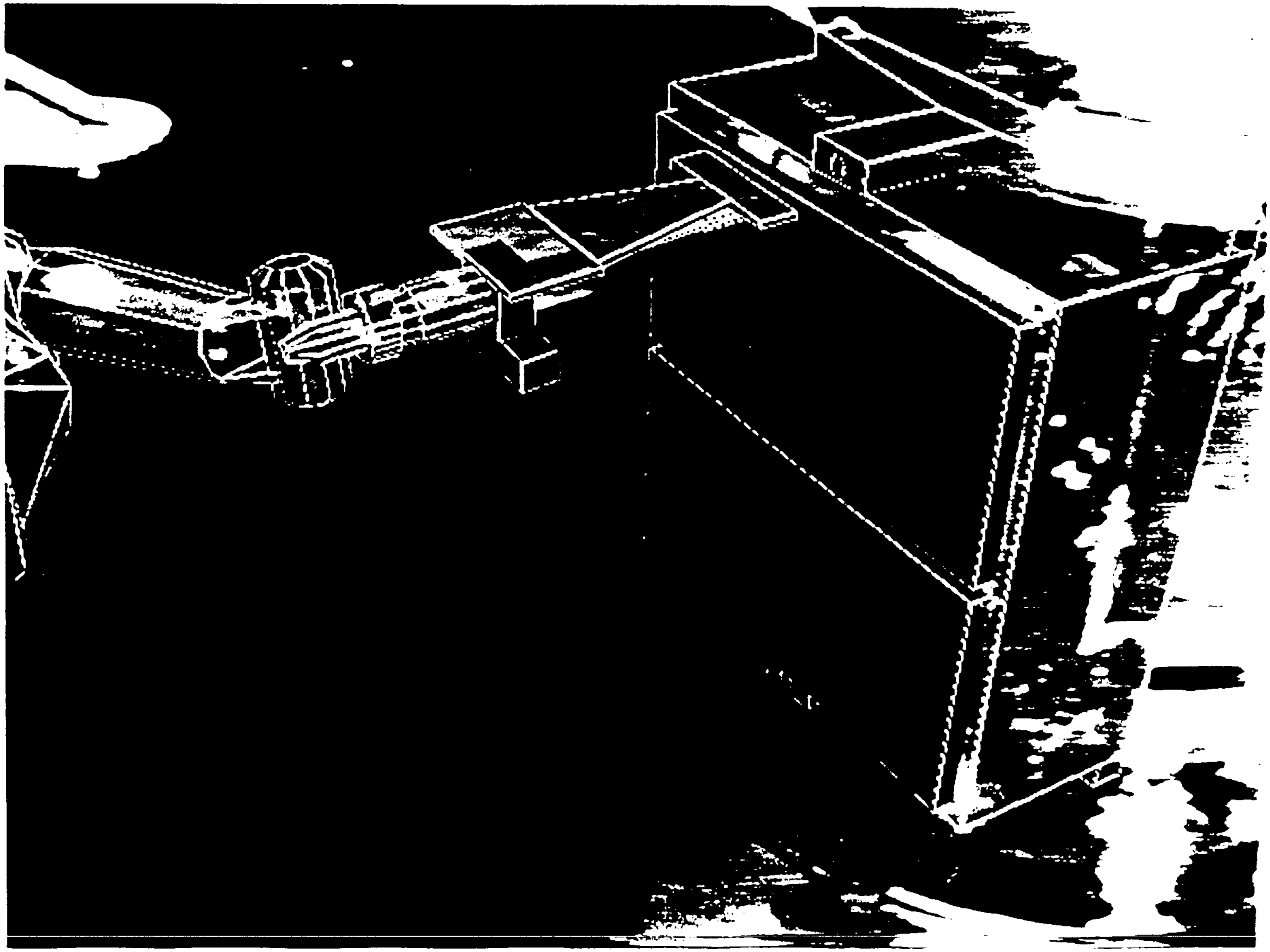
STATUS/ACCOMPLISHMENTS

- A HIGH FIDELITY 3-D CALIBRATION TECHNIQUE TO OVERLAY GRAPHICS IMAGES OVER ACTUAL TV IMAGES WAS DEMONSTRATED
    - PROVIDES REAL-TIME OPERATOR INTERACTION WITH OVERLAID IMAGES AGAINST THE REAL REMOTE WORK SCENE
    - PROVIDES HIGH FIDELITY SYNTHETIC VIEWS OF HIDDEN MOTIONS OR MOTION FOR WHICH VIEWS ARE NOT AVAILABLE
- DEMONSTRATED A HIGH FIDELITY/PREVIEW DISPLAY TECHNIQUE ON A SATELLITE SERVICING TASK AT GSFC, REMOTELY CONTROLLED FROM JPL
- A FUNDED JPL-INDUSTRY TECHNOLOGY. COOPERATION AGREEMENT AND IMPLEMENTATION PLAN WAS COMPLETED WHICH ENABLES THE COMMERCIALIZATION OF A COMPUTER GRAPHICS INDUSTRY PRODUCT

TECHNICAL CONTACT: A. Bejczy, (818) 354-4568

ADVANCED TELEOPERATION WITH CALIBRATED GRAPHICS OVERLAY FOR PREDICTIVE AND PREVIEW DISPLAYS IN REMOTE CONTROL WITH TIME DELAY

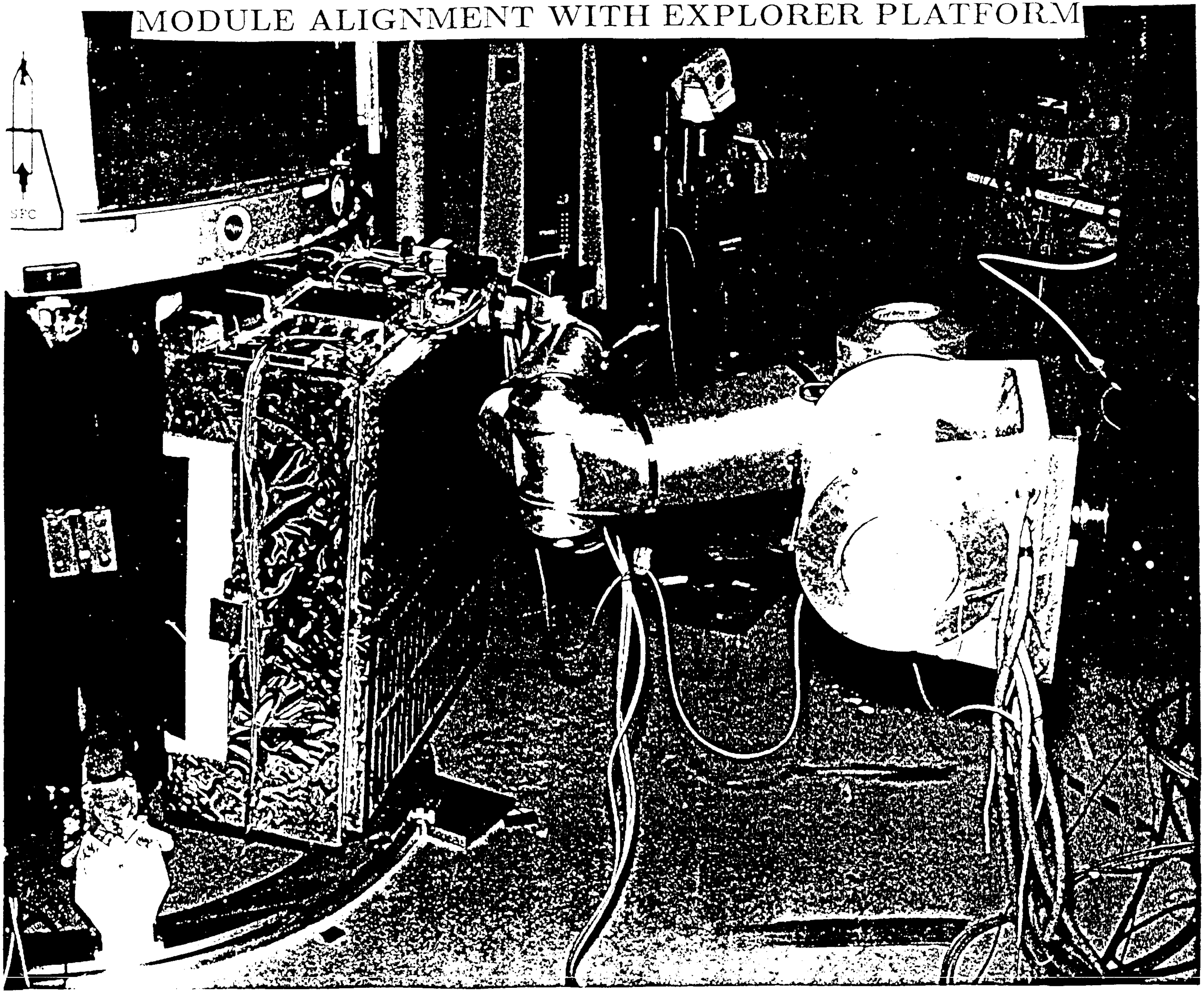
ORU EXCHANGE AT GSFC CONTROLLED FROM JPL THROUGH SATELLITE TV LINK



Robotic Servicing in Earth Orbit (GSFC)

- 1. Hubble Space Telescope has been designed and built for periodic on-orbit servicing
- 2. Currently, EVA is the mode of operation for servicing, but recent neutral buoyancy tests at MSFC have shown severe limitations on EVA time
- 3. HST project is developing a manipulator arm (Servicing Aid Tool) called SAT, targeted for the planned 1997 servicing mission
- 4. Autonomous robotic control for reducing crew involvement, for worksite preparation, ORU exchange, and post-EVA closeouts

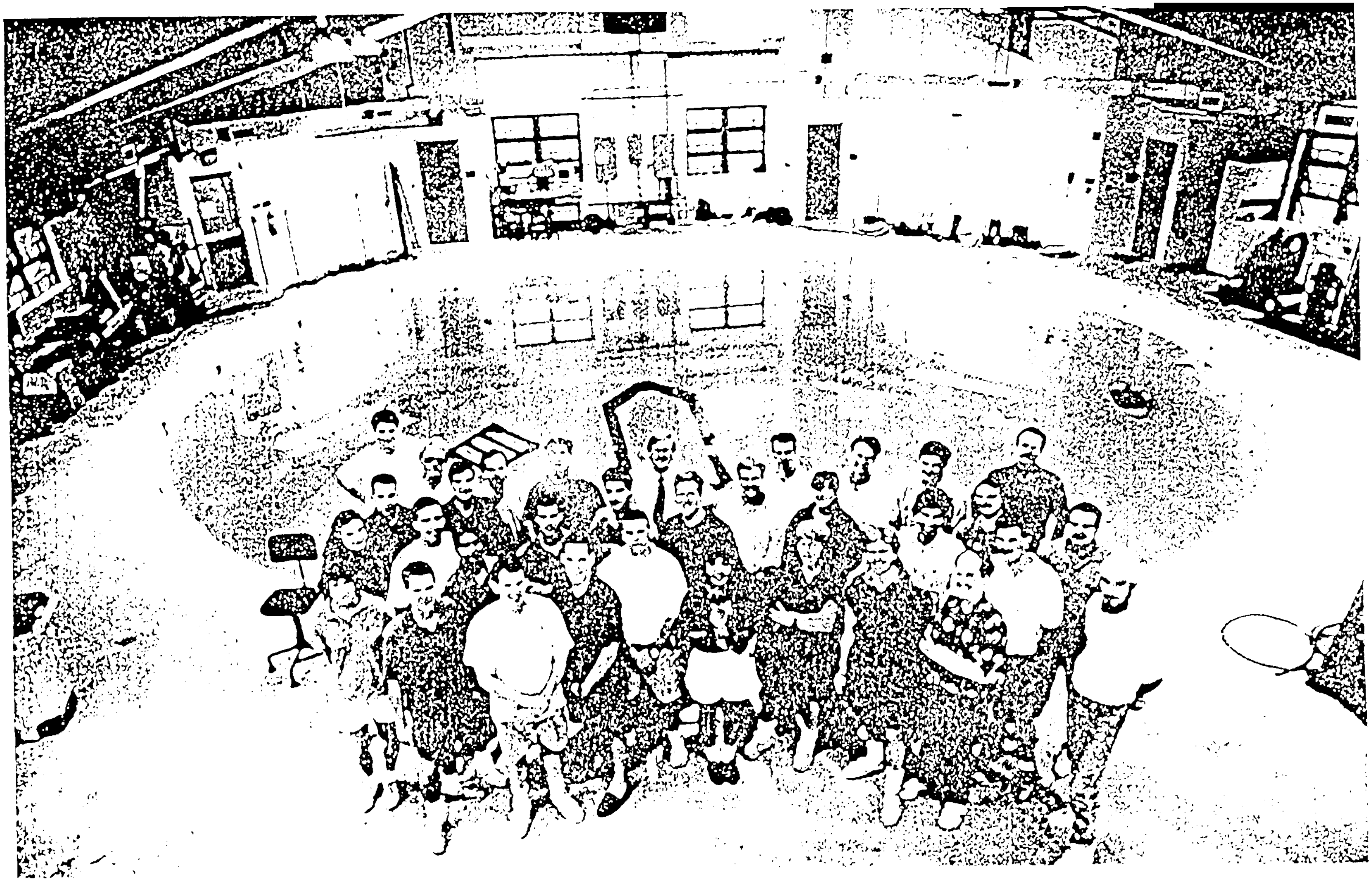
MODULE ALIGNMENT WITH EXPLORER PLATFORM



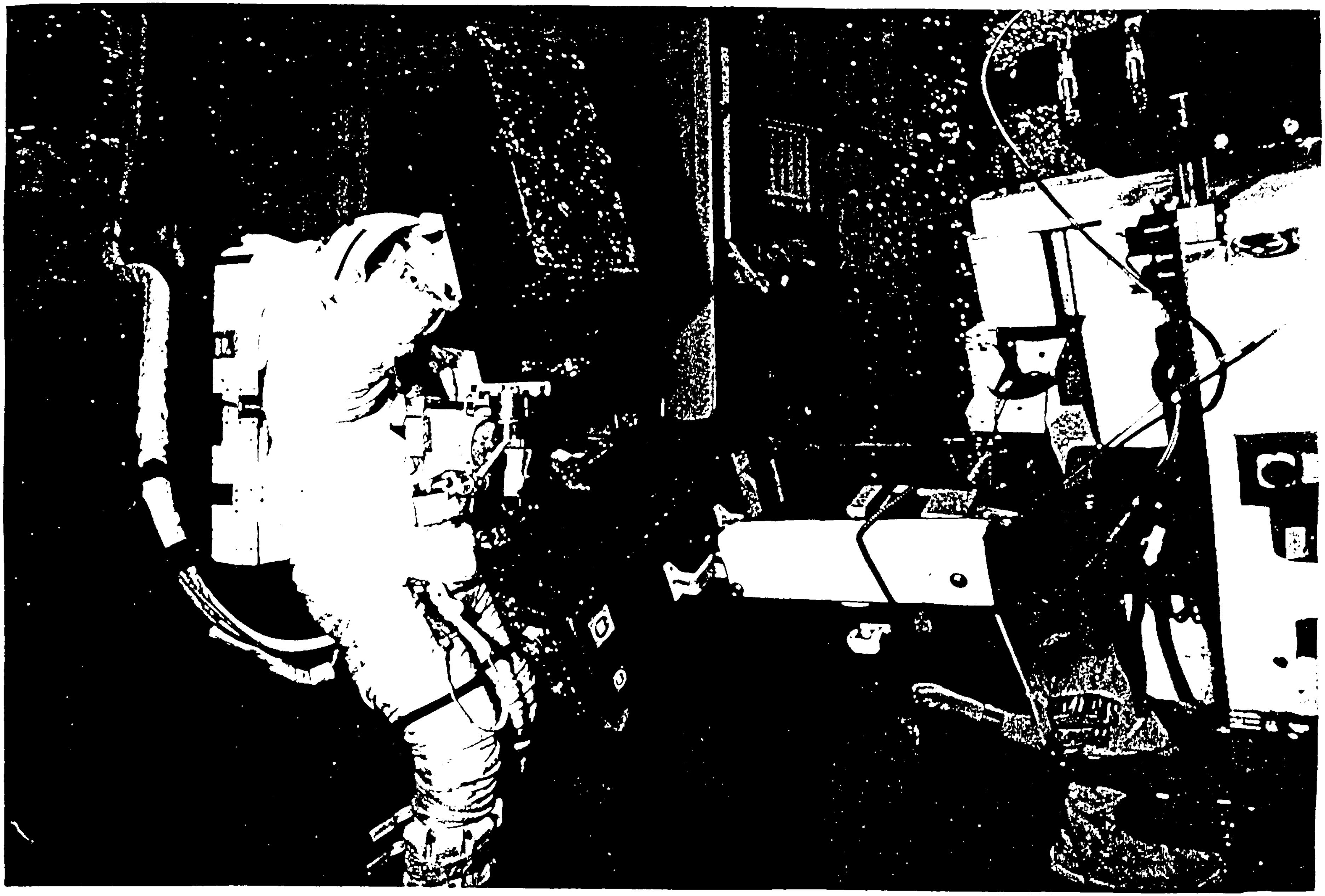
NEUTRAL BUOYANCY RESEARCH FACILITY (U. MARYLAND)

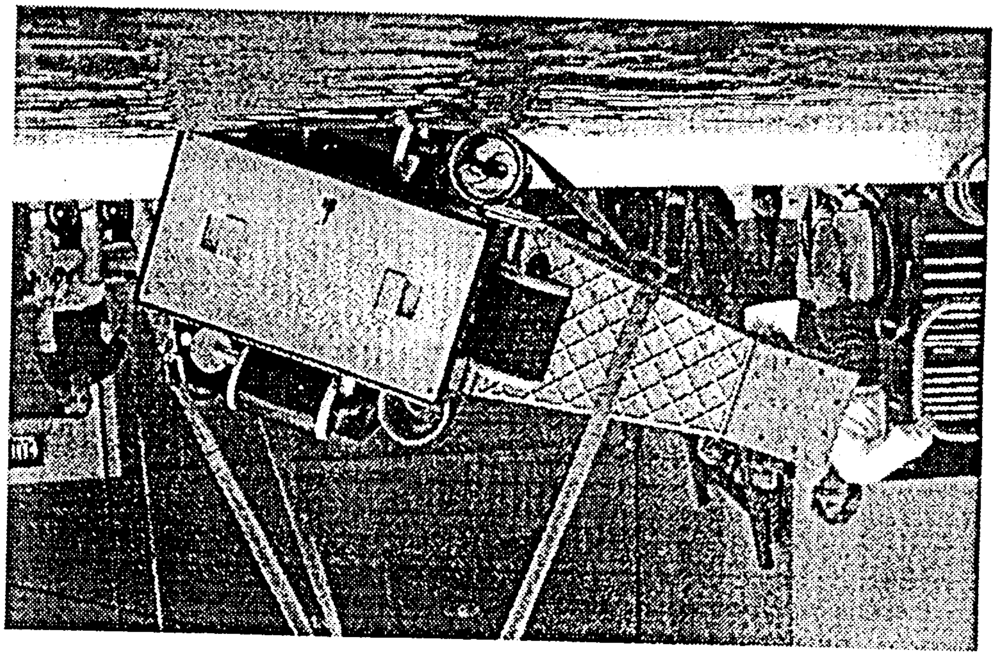
- Opened for checkout and test operations in August 1992
- Tailored for neutral buoyancy testing of telerobotic operations
- One of 4 US operational neutral buoyancy facilities
- 50 feet diameter, 25 feet deep water tank
- 367,000 gallons of water
- Simulate weightlessness of earth-orbital operations
- Test 6 telerobotic systems developed at the University of Maryland

Neutra Buoyancy Researc Fac y



SPACE OPERATIONS RESEARCH (U MARYLAND)
Hubble Space Telescope Cooperat ve Battery Changeout



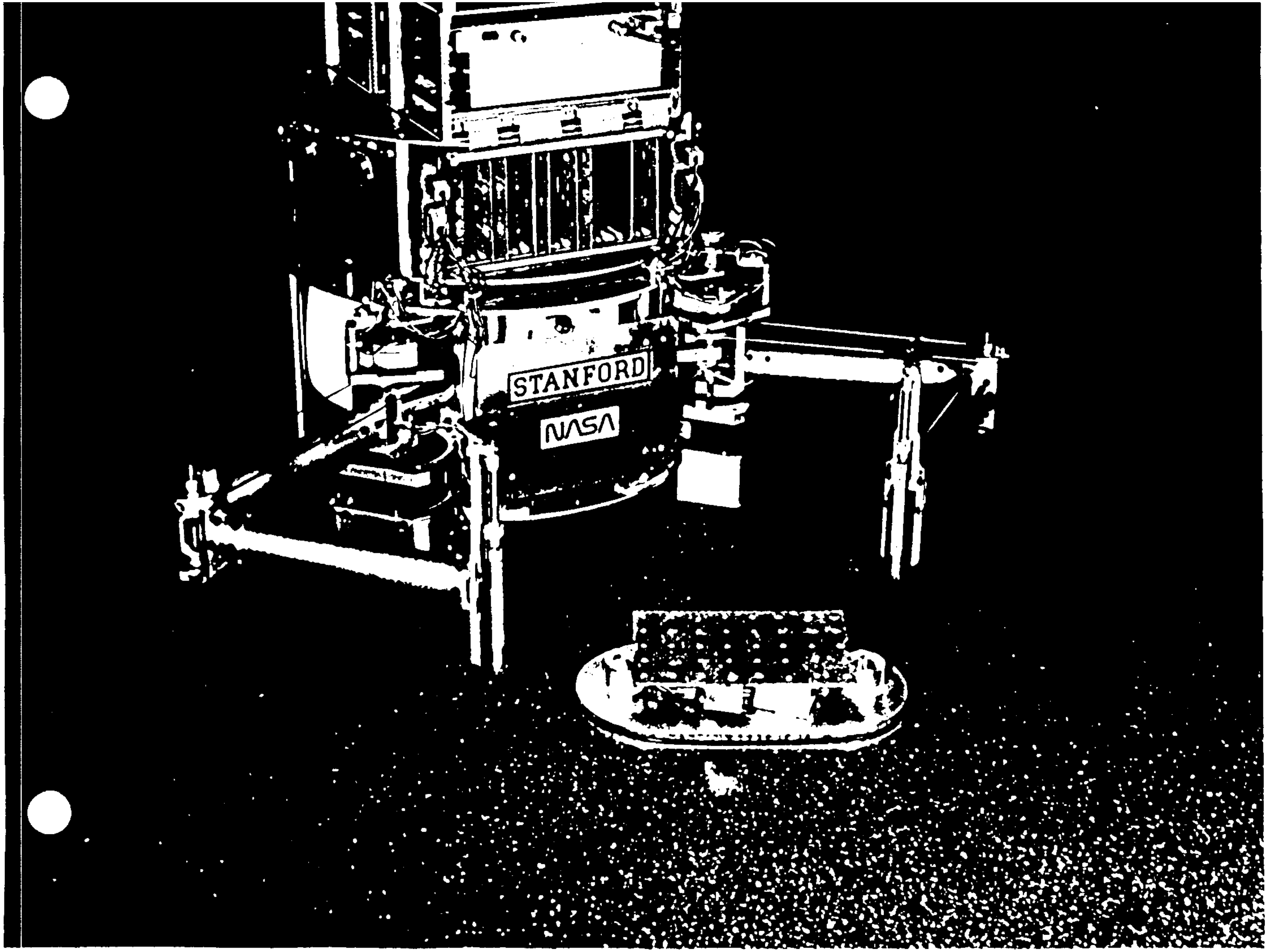


Ranger Vehicle Motivation

- 1, **Overview**
  - Developed as an underwater vehicle for telerobotic servicing simulation
  - Next generation lab vehicle based on BAT and MPOD
- 2. **Design Criteria**
  - Standard electronic interfaces to allow for expansion
  - Easily serviceable
  - Requirements for future space version launched on Pegasus
- 3. **Areas of Improvement**
  - Integrated buoyancy and balancing system
  - Stronger, stiffer manipulators
  - Interchangeable end-effecters
  - Greater computational power

Task Capabilities- Stanford

- 1. Semi-autonomous navigation with capture of free-flying object by free-flying robot with cooperating arms
- 2. Multiple cooperating robots for manipulation, transport, and assembly of large structures
- 3. Adaptive control: capture of objects with unknown mass
- 4. thrusterless locomotion


STANFORD
NASA

Upgrade Toward Operational Systems - Stanford

- 1. 3D dynamics simulator
- **2. 3D visual tracking of objects**
- 3. Global positioning system **sensor interface (develop and install GPS pseudolites which transmit GPS signal equivalent to orbiting** GPS **Satellite Constellation)**

New Robotic Systems and Experiments to Fly Before 2000

- **Canada**
  - Space Station Remote Manipulator System (55’; 7 DOF)
  - Special Purpose Dexterous Manipulator (two 7-DOF)
- **Japan**
  - Space Station Remote Manipulator Main Arm (6-DOF)
  - Small Fine Arm (6-DOF)
  - Free Flying Servicing Experiment (target and chase vehicles)
- **Russia**
  - Mars ’96: Marsokhod rover
- Germany
  - ROTEX

New Robotic Systems and Experiments to Fly Before 2000 (cont.)

- **United States**
  - Dexterous Orbiter Servicing System (7-DOF; Shuttle)
  - Ranger : dual arm free flyer
  - Charlotte: Science Payload Servicing
  - ROMPS: Robotic Operated Materials Processing System
  - Mars Pathfinder Rover
  - Lunar Rover (CMU-LunaCorp consortium)

IN-SPACE SERVICING NEAR-TERM CHALLENGES

- Demonstrate automated operation of remote dexterous robots from the ground
- Build libraries of robot skills and mechanisms for concatenization
- Implementation of sensory skills for obstacle avoidance
- Instrumented end effectors with improved dexterity

PLANETARY ROVER NEAR-TERM CHALLENGES

- Reliable navigation **of dense obstacle fields (Viking II)**
- **Real-time perception and mapping of multiple science targets/goals with high liklihood**
- **Mechanization of miniature sampling device** and control **of device from non-rigid base**
- **Sensing for over-the horizon navigation (geometric and non-geometric obstacles)**
- **Error recovery and resource management**
- **Strategies for site survey and efficient use of rover, lander, and ground locations**
- **Rover miniaturization**

ROBOT SYSTEMS GRAND CHALLENGES

- **ROBOT PLANETARY EXPLORERS WITH** COMMON SENSE (SURVEY SURFACES; RECOGNIZE, RETRIEVE **AND ANALYZE** SCIENCE SAMPLES)
  - autonomously confirm goal success
  - concatenate skills to achieve complex tasks
  - capability to learn and discover interesting things
- **MINIATURIZED ROBOTS WITH CAPABILITIES OF TODAY'S LARGE SYSTEMS**
  - core from a lightweight base
  - navigate large distances including verydense terrain, and beyond line of sight from lander

ROBOT SYSTEMS GRAND CHALLENGES (cont.)

- **FLY HUMAN-LIKE ROBOT THAT CAN BY ITSELF RETRIEVE, SERVICE, AND REPAIR** SATELLITES IN **EARTH ORBIT**
  - 3-D autonomous navigation
  - vision-guided rendezvous and docking
  - satellite grappling skills
- **FLY A ROBOT THAT CAN INSPECT, DIAGNOSE, AND REPAIR ITSELF**
  - automated inspection
  - real-time expert system diagnosis
  - dexterous manipulation
  - fault tolerance